AN ATLAS OF

AMPUTATIONS

By

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WITH 564 ILLUSTRATIONS

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To

MY WIFE

PREFACE

Amputation surgery had its inception in antiquity, and is the oldest of the surgical specialties. Evidence of it in form barbaric and primitive is revealed in the chronicles of ancient peoples and down through the annals of the past. But it was with the advent of gunpowder in the medieval period that amputations were first seen in great numbers and became almost routine procedure in the treatment of serious extremity wounds, and it has been only within the past millennium that the first accurate descriptive recordings have appeared. Among the first of these were the classic observations of Larrey in the Napoleonic Wars. However, it was not until the birth of anesthesia and the later evolution of antisepsis that highly specialized techniques could be developed. Many of these were incubated, hatched and died, lost within our archives, a few saw fruition and survived to be carried down through literature or to be passed on by word of mouth from one generation to another.

In the twentieth century, the onset of World War I brought quickened interest in amputations. Surgeons were again seeing these cases and were observing, and often recording, their findings, to pass their knowledge on. At this time Dr. Norman Kirk, later the Surgeon General of the Army, came forward to collect and segregate this material, and added many contributions of his own. With his keen insight and analytical mind he fathered amputation surgery and placed it on the sound surgical basis required. On this fundamental groundwork he and others worked to evaluate the different surgical methods and added others to their armamentarium. However, peacetime brings but few such cases to the average man, and so the second World War must come before another chapter based on mass experience could be added to the foundation which had been built so splendidly. Here again it was General Kirk who saw the need and established amputation centers. Here a group of younger men worked under the influence of his keen interest and enthusiasm. Old methods were re-evaluated, new techniques and principles were conceived and tested, mechanical progress slowly forged ahead. And so from World War I through World War II, present-day amputation evolved. It is no longer the ghoulish cutting off of a part, but rather it is a phase of reconstruction employing plastic and orthopedic surgery in delicate balance.

It is the purpose of this book to present to the reader those methods of the past which have stood the test of time and to add to these the fruits of recent experience in surgery, rehabilitation, and prosthetics. No attempt has been made to create an encyclopedia of amputation subjects, but rather, after review and evaluation, to present only those factors of practical significance. Stress has been placed throughout upon the importance of function in amputation at the various levels, and upon the fact that the course of amputation surgery does not terminate with closure of the surgical wound but extends through the fitting of the artificial limb and the successful rehabilitation of the patient.

For convenience the book has been divided into four parts *Orientation,* in which the definition, indications, and objectives of amputation surgery are discussed, *Surgical Considerations,* in which are presented the factors relative to wound healing, care of the individual tissues, surgical preparation, and anesthesia which are peculiar to amputation surgery, *Surgical Techniques,* in which the operative methods at each level are evaluated and put forth in step-by-step description, and the *Convalescent Period,* which includes complications, a photographically illustrated analysis of normal and amputee gait, a presentation of representative prostheses with emphasis upon the mechanical principles underlying their construction and the important steps to be taken in checking them for satisfactory fit and alignment, an outline of the various measures of physical medicine used in preparing and training the lower extremity amputee for the use of the artificial limb, a discussion of the retraining of the upper extremity amputee, and, finally, a word as to the amputee in sports

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APPRECIATIONS

This book, written and planned by an orthopedic surgeon who had the good fortune to be associated with large numbers of amputees at an army amputation center during World War II, would have lacked much of its comprehensiveness in information and illustration had it not been for those who gave so generously in their aid, suggestions, and contributions to this volume The stimulation of association and mutual interchange of information between the surgeons working in this field has been an invaluable asset in collecting, segregating, and evaluating the mass of material which was accumulated during and following the recent conflict Much of the material of this book is based upon recent published and unpublished work, while another large share is derived from the writings of the past A sincere effort has been made to give credit wherever it could be determined, but it is not unlikely that oversights have occurred If so, they have been unintentional and will gladly be corrected whenever they are discovered

Dr Leonard Peterson and Dr W H McGaw, whose constant encouragement and timely criticism and advice have always been a stimulus, have been an inciting force in the preparation of this work

To Dr Donald L Rose, who contributed the chapter on "Physical Medicine in the Treatment of Lower Extremity Amputations," and to Dr Emanuel M Papper, who contributed the chapter on "Anesthesia," I wish to express my gratitude

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To the photographic services of the Army Medical Department, to Mr C N Jones, the artist, and to Mr Gjon Mili, the photographer, I wish to extend my thanks for their aid in illustration

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And most of all, to my wife, Margaret Ann Slocum, who, with resolute and wholehearted cooperation, prepared and edited the major portion of this book, I tender my heartfelt appreciation

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An Atlas of Amputations

PART 1

ORIENTATION

I. ORIENTATION

The study of amputations cannot be limited to surgical considerations alone but must draw from the fields of general medicine, physical medicine, and therapeutics, as it follows the course of amputation from its inception through the completion of rehabilitation An amputation, as purely defined by the dictionary, is the removal of an extremity This definition, however, demands amplification here In the proper sense, amputation is the severance of an extremity through the continuity of the bone Should it occur or be performed through a joint, it is termed disarticulation There are three distinct classifications into which amputations fall surgical, traumatic, and congenital The first is one which is carried out deliberately by surgical means in order to sever from the body an extremity which is harmful or useless, the second is one which is done involuntarily by trauma, the third, congenital amputation, is one which is present at birth, due to maldevelopment of embryonic structures No matter what the etiology, it is the duty of the amputation surgeon to create, by his skill and judgment, a satisfactory stump with a maximum of function and comfort, to fit the patient with an adequate prosthesis and educate him in its proper use, and to aid him in his mental and emotional readjustment

Whenever the surgeon is faced with an extremity which is irreparably deformed, or severely involved by trauma, infection, or disease, he must always consider the advisability of amputation He should evaluate the situation in the light of the basic criteria for such a course Will the limb be able to fulfill its function? Will its presence greatly impair the health or endanger the life of the patient? Will its distortion disturb his mental and emotional balance? As in other fields of surgery, there is no 'rule of thumb'' to which he can refer in reaching his decision, with the single exception of the inviolable rule where the blood supply of a limb is destroyed, amputate When a limb has been deprived of its nutrition, it cannot live, and there are no circumstances which warrant its retention It must be removed, for not only is it useless but the products of tissue breakdown which it generates cause toxic effects throughout the body and endanger life Besides this one inflexible rule, there are, however

certain circumstances, or combinations of circumstances, which point toward amputation as the procedure of choice These general indications are (1) The need to rid the body of a useless extremity If, following trauma or infection, damage has been so extensive that function cannot be restored, the limb will be useless and should be removed If, in cases of congenital amputation, there has developed a short stub which is of no functional value, and which by its presence prevents the use of a workable prosthesis, it is better to eliminate such a stub, and provide the patient with a useful artificial limb (2) The presence of a malignancy within an extremity When a malignant growth, lying within an extremity, is extensive or is of an invasive type, it is seldom practical to remove it by excision Such a procedure may not completely eliminate the disease or, if it does, it may leave the limb deformed and useless Usually it is preferable to amputate the extremity and teach the patient to use a prosthesis (3) The presence of uncontrolled infection within an extremity If infection lies within a limb and cannot be controlled, that limb should be amputated It is a threat to the general health of the patient and often to life itself, either because of the toxins emanating from it, or because, if it is the fulminating type, it may invade other parts of the body If amputation is to be performed for the elimination of such infection or for the purpose of ridding the body of a malignancy, there is one requirement which it must fulfill It must, beyond any shadow of a doubt, eradicate the source of trouble (4) The above indications for amputation have been based upon the improvement of function or the saving of life There is, however, another aspect which is of equal importance That is the mental health of the individual Not infrequently, an extremity is so deformed at birth, or later through trauma, that it is repugnant Such an affliction may so distress its bearer that his mental state may approach psychosis This is particularly true of women with a hand distortion When such is the case, the removal of the offending part may restore the individual's mental equilibrium

In conjunction with the general indications for amputation, there are some general factors which the surgeon should take into account as he weighs the necessity or advisability of amputation surgery If prolonged orthopaedic treatment is the alternative to amputation, he should, as far as is possible, evaluate the anticipated end result and undertake the extended course only when he feels assured that the outcome will be as good or better than that which would be obtained by severing the part I have seen many a case in which months, or even years, have been spent and countless operations have been performed in an effort to save a limb which in the end has had less to offer in the way of comfort and function than a prosthesis would have had Examples are feet hopelessly deformed by crush injury or explosion, and distortion associated with nerve loss If long-term reconstructive surgery is undertaken with justifiable expectancy of a functioning limb, but it becomes apparent to the surgeon, before completion, that the result will not be gratifying, he should readily admit the vanity of proceeding further Aside from the futility of expending such time and effort to no avail, there must be considered the disturbing effect which such a course might have upon the economic status and psychological outlook of the patient Those two elements, the economic status and the psychological outlook of the patient, are important and must be reckoned with, for they are frequently the factors which determine whether the surgeon shall amputate or perform reconstructive surgery For one whose dependents look to him for sole support, the expense of long hospitalization repeated surgery, and days from the job weighs heavily That man must be satisfied that the end result will be func-

tionally worth his deprivations. If the loss of the affected part would in no way hinder his earning power, he might much prefer amputation and more immediate return to his work, to reconstruction and the expense and delay which it would entail. In contrast is the individual who could not follow his vocation were he to lose the injured part, such as a violinist whose fingers have been severely traumatized. This man could afford any amount of time necessary for repair better than he could afford the loss of his fingers. As for the psychological make-up of the patient, it, too, can play an equally decisive role. To some, prolonged hospitalization is demoralizing; it seems permanently to warp the pride and ambition so that adaptability to work is never regained. For such a one, amputation as a measure which would circumvent lengthy convalescence would be far wiser. On the other hand, there are some individuals to whom the very idea of amputation is appalling. If such an *idée fixe* exists in a psychiatrically unstable mind, to undertake amputation would be to court mental breakdown.

SPECIFIC INDICATIONS

Thus far, the discussion has dealt with the general principles behind the decision for amputation. Attention should now be directed toward more specific clinical indications. These will be grouped into the following categories and enlarged upon in that order: (1) trauma, (2) infection, (3) thermal injuries, (4) tumors, (5) nerve injuries, (6) peripheral vascular disease, and (7) congenital anomalies.

Trauma

Acute trauma is an indication for amputation when (1) it destroys the blood supply of an extremity, or (2) it results in damage so extensive or so mutilating that there can be no hope of reconstruction of a limb from a functional standpoint. The first condition, loss of blood supply, is usually obvious where severe laceration has taken place, but it may be difficult to determine in crushing or penetrating wounds. In the presence of that type of injury, every possible diagnostic aid should be employed. Even though these should not detect circulatory embarrassment, the case should be kept under close observation for any signs of gangrene. As to the loss of function through trauma, the surgeon must exercise his knowledge and his clinical judgment in evaluating the case. In many instances, although mutilation may be severe, the extent of destruction cannot be readily determined. There it is well to perform necessary débridement and to delay the decision for amputation until the degree of disability is more clearly defined and the possibilities of function following orthopaedic treatment can be more accurately adjudged. In many others the need for the removal of the extremity is self-evident, and surgery should be undertaken as soon as conditions permit. Very occasionally an industrial accident will effect amputation completely, or almost completely (traumatic amputation). In such an event, the wound should be treated as an open amputation without undue delay.

The sequelae of trauma are a different matter. Sometimes for lack of care, and sometimes in spite of care, complications may ensue. These may manifest themselves in the form of infection, nerve injuries, or more generalized ailments arising from toxic absorption from the injured part. Some of these sequelae may in their turn be sufficient cause for amputation. These will not be dealt with here but will be discussed under the categories in which they fall.

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Fig 1—Loss of blood supply, resulting from traumatic severance of a calcified posterior tibial vessel X-ray of a compound fracture of the tibia with extensive soft tissue damage

Fig 2—Loss of blood supply clinically evidenced by gangrene of the foot This was secondary to a perforating wound of the popliteal space, involving the great vessels (Walter Reed General Hospital Neg No 4616 2)

Fig 3—Same case showing the popliteal wound (Walter Reed General Hospital Neg No 4616 1)

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Fig 4—Irreparable tissue damage (Museum and Medical Arts Service Neg No CA 44158 Army Medical Museum)

Fig 5—Traumatic amputation of the thigh (Museum and Medical Arts Service Neg No CA 44144 Army Medical Museum)

Infection

There are two types of infection which, when not controllable by active surgical and therapeutic measures, are indications for amputation. One is the acute fulminating infection which threatens invasion of other parts of the body and thereby endangers life. The other is chronic infection, such as osteomyelitis which is a source of toxic absorption and jeopardizes the well-being of the patient.

When the rapidly ascending, fulminating type of infection is present, there is no question but that the limb in which it lies must be amputated, and amputated immediately. The most classic example of this type of sepsis is gas gangrene. (A word of caution should be inserted here. Before amputating, be sure that it is true gas gangrene of clostridial origin, and not simply a wound contamination, or localized cellulitis caused by other anaerobic pathogens. The latter are less insidious and require only débridement, or incision, with adequate drainage and general wound care. The inexperienced surgeon sometimes fails to make this differentiation and is too prone to remove a limb whenever he finds it invaded by gas. This is an error in judgment which frequently results in unnecessary loss of an extremity.) Occasionally, acute fulminating infection can be eliminated by radical muscle group excision, but this is only possible when the infection is well defined within a certain area and is only practical when i will not result in loss of function. The usual case involves several muscle group and demands such massive excision that the only logical course is removal o the limb. When amputation is elected, it should be high, radical, and of th open type. It is a lifesaving measure and, as such, has no place for conservatisn The surgeon must disregard the ideal site of election, and choose a level whic is well above the area of infection, where the muscles are contractile, have goo color and tone, and bleed normally. Frequently, disarticulation of the shoulde or hip has to be performed, and when this is the case, some additional muscl group excision may be required also in order to assure complete elimination o the sepsis. In the treatment of these fulminating infections, chemotherapeuti measures should always be taken. Gas antitoxin should be administered t neutralize the general effects of toxic absorption, and penicillin should be use to retard further invasion. The latter, it should be noted, will only act whe the circulation can carry it, and will not invade tissues which have been involve to such an extent that the blood supply is markedly impaired.

When there is within an extremity a chronic infection, one which has nc responded to all surgical and therapeutic measures for its control, amputatio must frequently be resorted to, though the indication for it is less clearly define than it is with the acute fulminating type. The chief danger of sepsis of lon standing lies in the toxins which it throws off and which are absorbed throughou the body with deleterious effects. The patient with a chronic infection shoul be closely observed for any evidence of degenerative changes, for they may b more severe than the appearance of the focus of infection would seem to warran They may result in amyloidosis, or a renal or cardiac condition which may wel be a more serious handicap than the loss of the limb, they may, in fact, endange the very life of the patient. If such a situation seems imminent, amputation i indicated on the basis of protecting the general health. Of the chronic infection which threaten such complications, osteomyelitis, or sepsis of the bone, is th most common found in the extremities. It is of two types, traumatic and hema togenous. Traumatic osteomyelitis is of external origin, that is, the invasiv organism has penetrated to the bone from without, through a break in the ski It is a frequent sequela of compound fractures, for, there, not only is the surfac

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ruptured but the continuity of the bone itself is interrupted This type of osteomyelitis is localized but is not always amenable to measures of control, and when it persists, it is a source of toxic absorption For this reason, and because of the length of time which treatment of such a condition would entail, amputation is often a more judicious course than orthopaedic procedures, even though a functional end result may be anticipated with the latter The other type, hematogenous osteomyelitis, is of internal origin, that is, the invasive organisms have been carried by the blood stream, and metastatic foci are usually present throughout the body Although these foci may long remain quiescent, they may be activated at any time For this reason, the elimination of a local site of infection, even by so radical a means as amputation, does not ensure that the disease is entirely eradicated, nor that the toxins from it are quelled Therefore, when general involvement is feared, amputation should be approached circumspectly

In addition to the grave effects which uncontrolled sepsis may have upon the body, there is the functional disability which it may cause within the limb itself Often, in the wake of infection, the surgeon will find extensive mutilation

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Fig 6—Multiple fractures, partial loss of the calcaneus, massive soft tissue loss, extensive cicatrization, equinus deformity, and motor and sensory loss on the plantar aspect of the foot, secondary to compound injury of the foot (Walter Reed General Hospital Neg No 4682 2)

Fig 7—Severe deformity of the foot accompanied by loss of bone and soft tissue, infection, and massive scarring (Walter Reed General Hospital Neg No 4578-3)

Fig 8—Loss of bone and soft tissue, and chronic infection, following compound injury of the forefoot (Walter Reed General Hospital Neg No 4810-3)

Fig 9—Chronic osteomyelitis, and complete motor and sensory loss in the forearm and hand, secondary to multiple compound, comminuted fractures of the elbow and upper forearm (Walter Reed General Hospital Neg No 4814-1)

Fig 10—Chronic osteomyelitis secondary to compound fracture of the tibia The circulation of the foot is poor, there is little active motion remaining in it, and sensation is lacking over its dorsum (Walter Reed General Hospital Neg No 4208-2)

Fig 11—Chronic osteomyelitis with multiple draining sinuses, and massive bone loss There is complete loss of function of the foot, and loss of sensation over its dorsum (Walter Reed General Hospital Neg No 4710 3)

Fig 12—Chronic suppurative infection of a finger with destruction of bone and soft tissue

Fig 13—Tuberculosis of the tarsus of an adult Negro, with multiple draining sinuses and secondary infection Elimination of the disease can only be accomplished by removal of the affected part (Walter Reed General Hospital Neg No 4598 1)

Even in a short period of time, infection may cause sloughing vast enough to impair function, and the longer it remains, the greater is the havoc it wreaks Muscles may become a fibrotic mass, tendons and tissues may become hopelessly cicatrized, bone may become necrotic and may form periosteal new bone and sequestra, blood vessels may become so tortured by scar that circulation is impaired In short, there may be such destruction that all function is gone and there is no hope of its restoration, or the surgeon may find that the extensive excision required to eliminate all effects of infection would leave the limb decimated beyond hope of functional repair In either instance, infection, or more accurately, the sequelae of infection, is an indication for amputation Tuberculosis is a classic example of this This persistent infection is commonly seen within an extremity and is frequently the etiological factor in amputation surgery When it is isolated, it is not too alarming for it can usually be controlled, or eliminated by moderate excision, before it has done irreparable damage, and any resultant disability can usually be corrected by orthopaedic measures (For this reason, its presence in children seldom leads to amputation, for the large capacity for resisting infection and regenerating tissue, which they possess tends to limit the extent of invasion) When there is diffuse involvement, however, control and reconstruction become more difficult and amputation is the most practical course in the majority of cases when there is severe mixed infection of bones and joints with multiple draining sinuses, eradication of the disease by any other means may be impossible, or if all structures are extensively invaded, massive excision may be necessary and function of the part may then be unsatisfactory, often, if prolonged conservative treatment can be carried out with any hope of success, the subsequent months of hospitalization would be fatal to the patient whose general condition is debilitated or toxic, or would prove too great an economic or mental strain The first two of these arguments almost invariably apply when the diffuse type of tuberculosis is present in the ankle or foot particularly the tarsus Experience has proved that when the calcaneous is invaded, when there is diffuse tuberculous involvement of all the tarsal bones, or when the ankle is affected and there are multiple draining sinuses and the inevitable mixed infection, the disease cannot be controlled by the usual orthopaedic measures, but excision of the affected structures is required Since such excessive surgery would render the foot hopelessly crippled, and since that part is not amenable to extensive reconstruction, it is apparent that amputation and the adaptation of an artificial foot are indicated as the more judicious course

Thermal Injuries

Amputation is occasionally indicated following severe burns when the tissues are involved beyond hope of future function It should be of the open type The level should be high enough to ensure the removal of all devitalized tissues which might become a source of toxic absorption and all deep structures which cannot be covered by healthy skin with normal sensation at the time of future plastic reconstruction Amputation may be advisable in the late treatment of burns where the limb is useless, or where function with a prosthesis would be superior to that with the reconstructed arm or leg Examples of such situations are severe contracture extensive fibrosis involving skin tendon and muscle and gross loss of skin from the sole of the foot In the last instance, continued function cannot be anticipated for extensive trophic changes result from the trauma of weight-bearing upon grafted skin

Gangrene is the primary reason for amputation in cold injuries Whether the etiology be ordinary frostbite high altitude frostbite immersion foot, or

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Figs 14, 15, and 16—High altitude frostbite of the hands Shown are the different stages through which the hands passed before the gangrenous areas were fully demarcated Note that if amputation had been undertaken prior to the final stage, a higher level would have been selected and valuable length would have been lost Topanah Army Air Field Fig 14 Neg No 413AB (36362) (548A) Fig 15 Neg No 413AB (46411) (701A) Fig 16 Neg No 413AB (46427) (718)

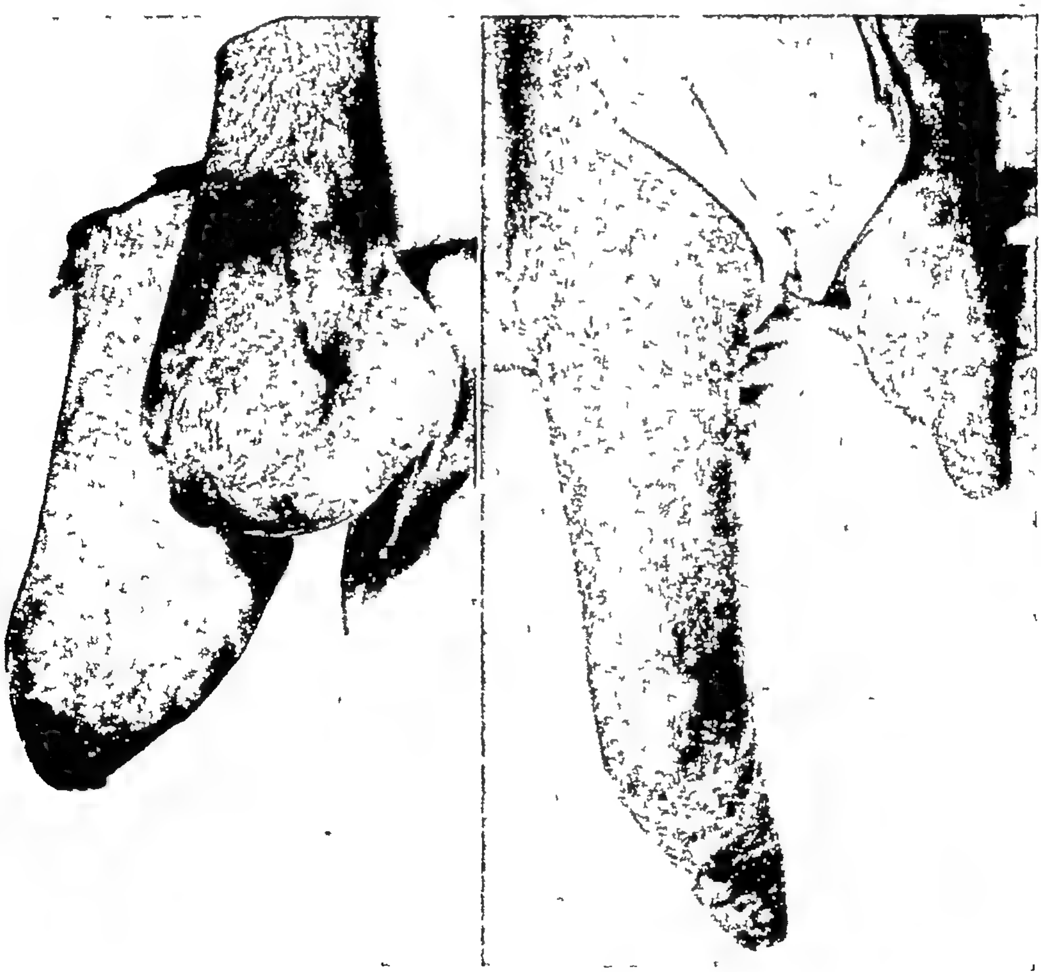

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Fig 17—Feet, frostbitten from prolonged exposure to cold with wet footwear, after necessary débridement of devitalized structures Final amputation is indicated to ensure suitable integument and to provide functional stumps (Walter Reed General Hospital Neg No 4384 3)

Fig 18—Lower extremities following severe gasoline burns incurred while patient was pinioned beneath aircraft wreckage Preliminary removal of charred structures has been performed, and a final type, bilateral amputation is indicated to form functional stumps (Walter Reed General Hospital Neg No 4522 2)

trench foot, the pathological changes leading to this condition are the same, namely, a diffuse fibrosis of all tissues from without inward, resulting in circulatory embarrassment and interstitial neuritis The more peripheral structures are involved to the greatest extent Amputation should be of the open type It should not be undertaken until gangrene is well demarcated and stationary, for, if it is performed before this time, valuable length may be lost through error in selecting the proper level Secondary plastic reconstruction of these cases is given special consideration in later sections of this text

In isolated instances, where only one foot is involved, amputation may be considered when weight-bearing results in extreme pain, due to the diffuse fibrosis of the nerve trunks and their terminal filaments

Tumors

A tumor may be benign or malignant If it is the former, amputation of the affected part is only indicated when excision of the neoplasm will result in a functionless limb If it is malignant, however, amputation may be necessary for the following reasons

1 To obviate further spread of the malignancy When amputation is considered as the means of eliminating a malignancy, it must be proved that the tumor is not of a type which can be treated satisfactorily by deep x-ray therapy, and that it is malignant beyond doubt A positive biopsy should be obtained (frozen section is seldom satisfactory in cases of bone tumor), for x-ray alone cannot be relied upon In order to eliminate the disease entirely, the extremity must be severed well above the tumor In some instances, such as malignancy of the upper end of the thigh with extension into the pelvis, this is not practical In such a case, amputation should not be done as a cure for the disease because it will not accomplish this purpose

2 To make the patient more comfortable If metastatic foci have already appeared elsewhere, and there is no hope for cure of the disease, amputation may still be carried out as a palliative measure when a malignant neoplasm is ulcerative and infected, and is causing considerable discomfort

3 To relieve excessive pain Again amputation may be indicated when the tumor has already metastasized, if the patient is experiencing great pain due to compression of nerves by the malignancy

When amputation is performed for the relief of pain or discomfort, there is one qualification which it must fulfill It must be at a high enough level that there will be no local recurrence

Peripheral Nerve Injuries

Amputation is sometimes indicated in the presence of trauma of peripheral nerves for the purpose of removing an anesthetic or a useless limb

Nerve injury may result in a limb which lacks sensation even though it is still functional Often such an extremity will develop trophic ulcers from repeated minor traumata of which the individual is unaware These are seldom amenable to treatment because of their indolent nature, and for this reason the anesthetic limb may have to be removed A particularly common example of this is amputation necessitated by irreparable damage to the sciatic nerve The usual history of such a case is that the individual will go on walking for several years with an anesthetic foot but that eventually trophic ulcers will develop, usually on the heel, as the result of a minor injury or repeated rubbing of an

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Fig 19 —Osteoblastic osteogenic sarcoma of the femur of a 5 year old girl Amputation was carried out at the level of the lesser tubercle

Fig 20 —Same case, five years later There was no evidence of recurrence of the tumor Note the bone growth within the stump (Courtesy of Dr Hugh Smith)

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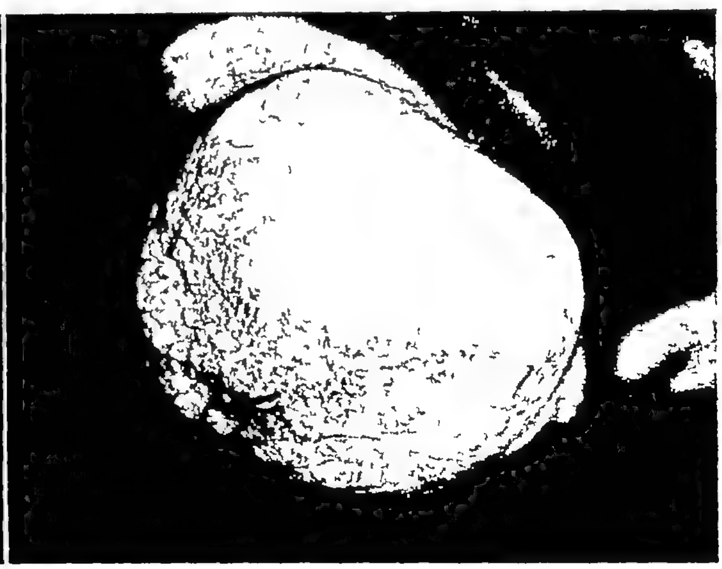

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Fig 21 —Markedly undifferentiated squamous cell carcinoma of the index finger without metastases Amputation was carried out in this instance to eliminate and prevent further spread of the malignancy (Walter Reed General Hospital Neg No 4581)

Fig 22 —Congenital vascular tumor, visible in the skin of an old amputation stump A portwine nevus of the leg was present at birth, it later spread and increased in size, causing an elephantiasis like swelling of the foot and ankle, and resulted in amputation at the age of 16 years Recurrence is evident in this photograph taken ten years later (Walter Reed General Hospital Neg No 4644-4)

Fig 23 —The terminal end of the same amputation stump, showing the verrucous, weeping character of the tumor at this point (Walter Reed General Hospital Neg No 4644 3)

Fig 24—Laceration of the brachial plexus which resulted in complete motor and sensory loss of the upper extremity Exploration revealed that the laceration was irreparable, and amputation was then indicated on the basis of removing a useless extremity Note the scar of the old injury at the anterolateral aspect of the neck, and the scar of the surgical wound which was used for exploration of the brachial plexus (Walter Reed General Hospital Neg No 4516 2)

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Fig 25—Charcot ankle following complete severance of the sciatic nerve in the mid thigh (Walter Reed General Hospital Neg No 4601 4)

Fig 26—Same case showing indolent ulcer of the heel Amputation was carried out at the supracondylar level above the area of sensory loss Most cases of complete sciatic nerve loss eventually come to amputation because of the complete motor and sensory loss of the lower leg, and the accompanying ulceration and infection (Walter Reed General Hospital Neg No 4601 1)

ill-fitting shoe This will usually occur after a time in spite of conscientious foot care and careful selection of footwear In these cases amputation is indicated above the knee at a level where sensation is intact Although this situation is seen less frequently in the upper extremities where the constant trauma of weight-bearing is not present it is not uncommon to find asensitive fingers caused by median and ulnar nerve injuries When these develop indolent ulcers following minor trauma or burns, they, too require amputation

When multiple nerve injury occurs such as impairment of the brachial plexus an extremity may lose both sensation and motor power Such a limb creates no harmful effects within the body but being useless it may be very much in the way and it may cause pain because of its weight dragging on the sensitive structures which support it Its functional worth cannot be replaced by a prosthesis since the motivating power for such a device is destroyed, and for this reason, the patient may wish to retain it for the sake of cosmesis, especially if it is not painful The surgeon should first ascertain whether or not the damage is irreparable, and if it is weigh the nuisance value of the limb against its cosmetic value

Occasionally, in the forearm and hand, severe soft tissue damage and deformity will be associated with nerve trauma, and this combination of disabilities may warrant amputation where one or the other alone would not justify it

The matter of amputation in the paraplegic demands special attention It should not be undertaken if the patient can be rehabilitated through training in the use of braces and crutches, for even though his legs are functionless, they aid him in maintaining balance However, the picture is different if there are severe flexion contractures of both knees and hips which have not responded to physical therapy and in which orthopaedic correction is not feasible In such a case, the patient will be bedridden and will eventually be afflicted by the inevitable urinary involvement and pressure sores The removal of his limbs, which serve no purpose whatsoever, will spare him this Given a thorough explanation such a patient will have the proper psychological attitude and will probably find welcome relief in the elimination of his useless and cumbersome extremities

Peripheral Vascular Disease

Peripheral vascular disease is usually a part of a generalized process, having its chief clinical manifestation in the lower extremities It most frequently occurs as a result of arteriosclerosis, arteriosclerosis in combination with diabetes, or thromboangiitis obliterans In the study of these cases, observation and treatment of the extremities alone is not enough since, frequently, cardiac, renal, and cerebrovascular changes are taking place concomitantly As the present discussion is not concerned with medical treatment, suffice it to say that such a patient in whom amputation is considered should be under strict medical control, and that surgery, when indicated, should be undertaken with thorough understanding of the pathological processes involved and should be executed carefully and without undue delay

When circulation is impaired, the chances of throwing off infection are limited and wound healing is uncertain For these reasons, even minor infection or trauma of an extremity may warrant its removal when peripheral vascular disease is in evidence Amputation of the toes or metatarsal bones may be indicated for minor infection, osteomyelitis of a toe, or for gangrene of the tip of a toe, or it may have to be undertaken in order to eliminate a toe subject to

callhuses or ulceration or to secure adequate drainage for sepsis about the base of a toe In such cases there are two criteria which must be fulfilled (1) The general condition of the patient must be good enough to warrant the risk of possible spreading infection (2) The circulation in the foot must be sufficient to allow wound healing, following surgery, in order to obviate as much as possible the further extension of infection into the fascial spaces. There must be normal dorsalis pedis pulse, normal skin temperature good color and nutrition normal color on dependency of the extremity, absence of ischemic pain, and positive assurance that infection is localized and minimal If any one of these requirements is not met, amputation should not be done through the forefoot but should be carried out at a higher level

In the presence of extensive gangrene or infection, and in those cases where amputation through the forefoot is inadvisable, the site of choice is above the knee (Experience has shown that below-knee stumps, in cases of this type, will invariably break down after a year or two, even though they may appear excellent immediately following operation) The single exception to this rule is in cases of thromboangiitis obliterans when the other extremity has been lost, or its removal is anticipated Even then, circulation must appear to be adequate

Fig 27—Thromboangiitis obliterans with vascular insufficiency and infection of the forefoot In this case the opposite extremity had been previously amputated above the knee because of gangrene of the foot, and minor amputation had been undertaken here in an effort to save this remaining extremity With the failure of this procedure, amputation above the knee is indicated (Walter Reed General Hospital Neg No 46382)

In the presence of peripheral vascular disease, the decision for the open or the closed type of amputation is influenced by the status of the infection and by the distance at which the site of severance lies above the affected area The closed type is only indicated where the infection is minor, or well localized and lies well below the site selected for the surgical procedure The open type should always be employed when severance is to be carried out just proximal to the affected part, or when the sepsis is severe and extends upward through the lymphatic channels to the proposed level of operation As with amputations based on other indications it is always advisable to use the open type of procedure when the patient is critically ill and the infected extremity must be removed to save life, for, here speed under anesthesia is essential

Congenital Anomalies

Congenital amputation is due to failure of development of the limb bud Usually the stump is not smooth and well-rounded, as in the ideal surgical amputation, but has upon it an extra bud, or protrusion, which often contains bony elements For this reason surgical interference is often indicated to improve the form of the congenital amputation stump so that it can be fitted with an artificial limb The location of these protrusions largely determines the level of the surgical procedure, but the fact that the soft tissues are generally fibrotic, due to the lack of functional development of the muscles and their related structures, influences the type and extent of the plastic repair to be undertaken Thus, there can be no standardization of technique, but the general principles of plastic surgery should be followed

The congenital deformities which indicate amputation are the complete or partial absence of the long bones, the congenital contractures, the congenital tumors, and the presence of supernumerary digits When orthopaedic procedures are of no avail, amputation surgery, consisting of remodeling the end of the limb, should be undertaken so that the extremity can be adapted to a prosthesis In the presence of congenital contractures associated with severe distortion, or when there are conditions such as congenital pseudoarthrosis of the tibia or advanced congenital paralytic deformities, every effort should be made to restore the function of the limb by reconstructive orthopaedic surgery If this course fails, amputation should be resorted to without undue delay Congenital tumors are rarely malignant, but if they are, they are an indication for amputation on the same basis as those which occur after birth Benign congenital tumors should be amputated only when the patient has little or no function of the limb because of them, and when involvement is so extensive that excision and reconstructive measures are not feasible Supernumerary digits should be removed when their presence interferes with function or when they are a cosmetic affliction even though they do not impair the utility of the part

Since, by their origin, afflictions of this nature are present at birth, the question of their surgical revision usually arises during childhood, and since, due to the circumstances, surgery in such instances is an elective procedure, there is posed the problem of determining at what stage of growth it should be undertaken This has often been a matter of debate Some feel that it should be early, and some contend that it should be delayed until growth has ceased The vagaries of growth under such circumstances do present a peculiar problem in the face of amputation, but allowance can be made for them by variations in the surgical technique True, when amputation is performed during the growing period, there is a discrepancy between the general growth of the stump and that of the normal limb, but that may be compensated for in the construction of the prosthesis All things considered, the writer feels that amputation should be undertaken as soon as a positive indication occurs The child may be fitted with an artificial limb as soon as he is of walking age, and he adapts himself well to the use of such a device for there is in children a natural aggressiveness and a lack of self-consciousness Aside from this purely functional consideration, there is the psychological aspect of the situation The handicapped child cannot take part successfully in all the activities which his associates enjoy, and the very presence of the deformed member creates a stigma which is amplified by the social intolerance of his playmates The removal of the crippled extremity and the substitution of a functional artificial limb will enable that child to do many things of which he was incapable before and will give him an appearance of normalcy The sooner this can be accomplished, the better are his chances for

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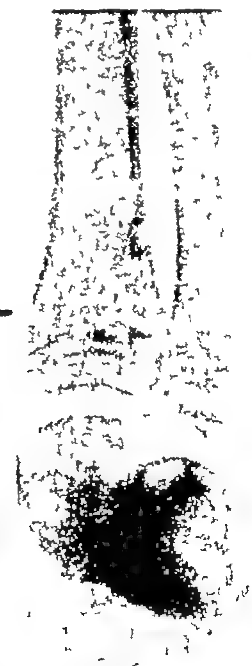
28 29

Fig 28—Supernumerary digits Functional reconstruction of a hand frequently involves amputation of one or more rays in combination with plastic procedures

Fig 29—Congenital amputation of fingers and toes Plastic reconstruction of the hand was necessary, no reconstruction of the feet was necessary, since they were satisfactory in ordinary footwear



30 31

Figs 30 and 31—Congenital amputation of the forefoot Such an anomaly may occur at any level and frequently presents protrusions of skin or bone which must be removed to allow for the adaptation of a prosthesis

good social adjustment. Occasionally in congenital amputation, the stump will be such that it can assume a specially constructed prosthesis as it is. In this instance, surgical amputation and repair may be delayed until growth has been attained.

ULTIMATE GOAL

While the primary objective of amputation surgery is to remove an extremity which is useless or which endangers the life or health of the individual, the ultimate goal is the successful rehabilitation of the patient back into the normal life of his community. This goal can only be realized when a satisfactory, durable stump has been formed, a comfortable, well-constructed prosthesis has been selected and properly fitted, and the amputee has been diligently trained in its effectual use and has been carefully guided toward a healthy mental attitude. These four factors—the good stump, the functional, well-fitted prosthesis, proper training in the use of the artificial limb, and sound psychological adjustment—are mutually interdependent, and it cannot be overemphasized that each is of profound importance.

The good stump is one which is durable, comfortable, and functional. Ideally it will possess certain attributes. Its bone end will fall at the site of election of the limb segment involved (that point, experience has proved, at which severance results in the most functional stump) or within the area of election (the adjacent area just proximal to the site of election), for there the tissues afforded for padding and integument are best suited to withstand the trauma of use, and the resultant stump length is that which provides the most effective lever arm and is the most readily fitted by a sightly prosthesis or is the most useful in itself if a prosthetic device is not to be worn. It will be tailored to a smooth even contour. If amputation is performed through the continuity of the bone, it will be gently tapering in shape; if severance is carried out through the distal end of the bone, as in the end-bearing amputations of the lower extremity, it will present a broad, smooth weight-bearing surface at its distal end. The surgical scar will be linear, well healed, and nonadherent, and will lie transversely across the end of the stump, or just proximal to it in the case of the end-bearing amputations. It will be covered with skin which has normal tone and sensation, is freely movable, and fits snugly with normal tension over its distal end. There will be no puckering, deep skin folds, "dog ears," or redundant masses of skin and muscle. Circulation will be normal. Edema will be absent. There will be neither tenderness nor pain, and the joints lying proximally will have full range of motion, unrestricted by contracture and activated by well-balanced, powerful musculature, so that the stump may be placed in any position with comfort and ease.

In the creation of a stump which approximates this ideal, the initial concern of the surgeon is to determine the type of procedure which should be undertaken. This depends largely upon the attendant circumstances. When actual or potential infection is present, it is not practical to fashion the stump in its final form and to close the surgical wound, for wound breakdown, tissue slough, and subsequent loss of length will inevitably occur. Rather, open amputation should be performed as a temporary procedure to remove the septic and necrotic elements and to allow the tissues to return to normal before final definitive surgery is undertaken; it should always be carried out at the most distal site which is practical so that all possible bone length and tissue may be maintained. When the surgical field is clean, either at the time of the initial procedure, or subsequent to open amputation, the closed or final type may be performed. Whenever circumstances will permit, it should be undertaken at the site of election

and the stump should be tailored and the amputation wound closed in accordance with the standard technique for the level selected Not infrequently, severe trauma or infection will have resulted in loss of bone length or tissue slough, and special plastic measures may have to be carried out in order to provide adequate normal tissues and integument, or the final stump may have to be formed proximal to the site of election If such is the case, the basic requirements of the good functional stump should be kept in mind and every effort made to fulfill them Following final surgery, postoperative care is directed first toward sound wound healing Later, the stump is shrunk by bandaging, muscles are strengthened, and contractures are eliminated, and any other measures necessary to prepare it for future usefulness are undertaken

The truly useful prosthesis is one which meets the demands of the individual, whether they be utilitarian or cosmetic, and which has been adjusted and aligned with careful attention to his idiosyncrasies Generally speaking, the selection of the artificial limb is made upon the basis of its construction and its adherence to sound mechanical principles, and impractical or untried gadgets and gimcracks are best avoided, more specifically, the choice is founded upon the limb's suitability to the individual with respect to age, sex, physical and mental capabilities, and upon its adaptability to the climactic environment and to the occupational and cosmetic demands which will be placed upon it The adaptation and the fitting and alignment of the limb go hand in hand with its selection They are undertaken once the stump is soundly healed and any complications have been corrected, and repeated readjustments are frequently required over a considerable period Careful attention must be given throughout to the peculiarities of the stump and of the individual, and this demands expertness on the part of the limb fitter and patience and cooperation on the part of the amputee They should be satisfied with nothing less than perfection, for only when the prosthesis can be worn with comfort and can perform as it was designed to perform can the patient be trained in its proper use and troublesome complications be avoided

Training in the use of the artificial limb should lay stress upon the effectual handling of the prosthesis and the mastering of the essential skills which are required of the individual It should consist of the presentation of the proper methods of usage and the correction of faulty habits It is best carried out upon a progressive plan with frequent checks upon achievement, and it should be continued until the amputee has attained the greatest proficiency of which he is capable, for it is the last step in his physical rehabilitation before he returns to normal life

It is to be hoped that, with careful guidance, the mental and emotional readjustment of the amputee will have kept pace with his physical progress There is little doubt that the loss of a limb is attended by severe psychic trauma, and there is equally little doubt that the treatment of such trauma is essential to the physical and social rehabilitation of the individual If he is to re-establish his economic and social status, he must become self-sufficient and self-confident, that is to say that he must become adept at the tasks required of him, either with or without a prosthesis as the case may be, and must accept, and be at ease with, his abnormality Both the proficiency in performing necessary tasks and the ability to accept his limitations and live within them require a healthy mental attitude Such an attitude is not easily come by, but must be nurtured throughout the course of amputation surgery by the physician's solicitous insight into the emotional background of the amputee and his patient administration of timely psychiatric therapy There is no standard treatment which can be set forth, because the human variable is ever present Observation has shown, how-

ever, that similar reactions seem to occur in those of like circumstances, and that certain patterns of reactions are generally to be found during the different periods following the inception of amputation It is the purpose of the following pages to point out these general similarities in reaction and these common patterns

The general circumstances of the amputee—age, economic and marital status, occupation—tend to influence his reactions to the loss of an extremity Those in the younger age group usually have difficulty in adjusting themselves to amputation, for they foresee a loss of all normal activities, such as sports and family life, and they fear for their economic future, whereas older individuals accept the loss with greater equanimity, for they are seldom keenly interested in participating in active sports, their family life is more apt to be settled and to have stood the test of time and varying fortune, and their economic status is more likely to be stable so that they know they will be taken care of either by their own resources or through some responsible agencies With regard to economic uncertainty, concern and anxiety are usually directly related to the site of amputation and the effect of the loss upon the individual's ability to resume his usual occupation In this respect, vocational readjustment is more easily obtained in the professional man and the cleric than in the one who has lived by manual or skilled labor No matter what the background of the amputee, uncertainty and fear of the unknown must not be allowed to take root and flourish, for they are the basis of psychosis The surgeon should make an honest attempt to draw forth the multitude of questions which torment the patient and to answer them patiently and fully He should explain clearly the factors which necessitate removal of the limb, the steps which are to follow and their purpose, the appearance, function, and limitations of the prosthesis, and he should help the amputee to appreciate his future possibilities and understand his future limitations, that he may evaluate his situation and adjust himself to it

As was noted above, there are certain types of reactions which commonly occur during each period of the long and varied course of amputation surgery—the initial period of realization, the postsurgical and preprosthetic period of adjustment, the period of prosthetic training, and the period of social and occupational rehabilitation

The initial reaction to loss of a limb depends to a large extent upon the circumstances under which the amputation has occurred Where it follows immediately upon acute trauma, the initial acceptance of the fact is somewhat simplified, for it is a case of emergency, not elective, surgery Should the patient be conscious, he has not the time nor clarity of mind to dwell upon the forthcoming problems and ramifications but is aware only that amputation is necessary to rid him of a hopelessly mutilated part or to save his life If he has lost consciousness, as is the case in many instances, the amputation may be an accomplished fact before he is even aware of its necessity Under such circumstances, upon regaining consciousness, one may feel that the limb has gone "numb," particularly following sudden severe trauma occasioned by the striking blow of a missile, or brought about through vehicular or industrial equipment, another may not realize the loss of the extremity until he tries to use it When realization comes, the reaction is usually as follows fear of imminent death, state of indifference in which the patient seems not to care whether he lives or dies, compensatory minimization of the injury as manifested by laughing, joking, cursing, or boisterous talk, or a feeling of luck and gratitude that he is still alive Seldom does pain immediately after injury seem to be a serious consideration

When amputation is delayed, reactions are somewhat different The majority of delayed amputations come as a sequel to severe extremity injury, such as a compound fracture from which osteomyelitis or irreparable deformity has re-

sulted, and they usually follow extensive orthopaedic treatment prolonged over a period of months or even years. The decision to terminate this unsuccessful treatment in favor of amputation is met by two types of reaction: relief at the final riddance of a useless limb which has been subjected to repeated surgical failures, or severe disappointment at the ultimate loss of the limb after such discomfort and inconvenience have been undergone. In cases in which orthopaedic treatment is being undertaken in the face of tremendous odds, and where amputation may have to be performed eventually, it is far better for the surgeon to prepare the patient adequately for such a possibility so that he may realize that everything has been done to avert it, than to fail to give due warning and risk invoking unfavorable criticism and reaction. The situation differs when delayed amputation comes in the wake of peripheral vascular disease, for there the possible involvement of an extremity in connection with the disease may have been apparent but there has been no thought of eventual amputation. In the majority of such cases, the rationalization of the patient is further complicated by the fact that above-knee amputation is likely to be necessary even though the trauma or infection involves only a few toes or the forefoot. Those in the older age group frequently accept this as a consequence of age, but those in the younger groups have been seen to develop persecution complexes with potentially suicidal depression in the face of it. If a satisfactory mental adjustment is to be made, there must be a careful and painstaking explanation of the situation to the patient so that he may realize the validity of the decision and appreciate that amputation is necessary as a lifesaving measure. It is well to stress the fact that the patient need not be reduced to the status of a cripple nor to a wheel-chair existence, but that his rehabilitation may be anticipated if he has been previously active. Of course, such an approach would be inadvisable if the patient had been in advanced stages of debility prior to the necessity for amputation and would not, under any circumstances, be expected to attain this goal.

After the amputation has been performed and the patient has recovered sufficiently to reflect upon his physical situation, it is not uncommon to observe the development of a tension state based on uncertainty as to what lies ahead. If the primary procedure has been an open amputation, the patient should be afforded, during this postoperative period, if not before, an understanding of the course which is to ensue. He should be made to realize that the initial operation was a temporary step to make possible the creation of a good, durable stump when conditions were more favorable, and he should be made aware of the end toward which the surgeon is working, that he may accept with better grace and greater cooperation the subsequent steps which are necessary to attain it. If the original operation was of the final type, discussion of forthcoming treatment need only be concerned with the therapeutic measures which remain to be taken in preparation of the stump for future use. No matter what the type of amputation, however, this period between surgery and the training in the use of the limb is usually one of confusion, in which the amputee may react by depression, resentment, anxiety, defiance, cheerfulness, resignation, or indifference, and in many instances may run the full gamut of all these mental states. This dilemma, though it varies in intensity with the individual and his environment, is based upon lost security and arises through the patient's doubts as to his ability to cope with future situations, limited as he is by his new physical handicap. The most common of the problems which confound him are, seriatim:

1. The extent to which he will become an object of curiosity and sympathy. This brings up the question of his future relations and association with his family, friends, and community, and the question of physical appearance in relation to employability.

2 The effect of amputation upon sex relations This problem is threefold (a) the question of acceptability to wife or sweetheart, (b) the question of physical relationship with the opposite sex, and (c) the question of hereditary transmission of the acquired physical defect It is well to instruct the amputee that there is no deviation from normalcy in his situation, other than the loss of a limb

3 The effect of amputation upon life expectancy Here again the amputee is like other normal individuals, and the amputation itself has no particular bearing upon the length of life

4 The degree of disability which will be present Many an amputee, particularly when group association is not present, fears becoming a cripple, confined to a wheel chair or crutches, or dependent upon others for the performance of everyday tasks Much can be done to reassure him by introducing him to the artificial limb Many do not know that an artificial limb has joints and hinges which enable it to simulate natural motion of the normal extremity The patient may visualize the old-fashioned peg leg of John Silver in *Treasure Island,* or the inefficient bailing-hook hand of the Barbary Coast pirates The opportunity should be provided for him to see and study prosthetic devices so that he may know what to expect and what is to be expected of him By careful and thorough explanation of the fitting and use of the artificial limb, the patient will be prepared for its inadequacies and his own ineptness But yet there will be many questions which he will ask (and many more which must be drawn from him) and which should be answered fully, no matter how inconsequential some may seem, such as Is the prosthesis worn day and night? Does one remove it when bathing or going swimming?

5 The effect which his physical limitations will have upon his ability to undertake the occupation for which he is trained or the vocation of his choice Although in this period it is not possible to anticipate the degree of proficiency which he will attain with the prosthesis or the amount of endurance which he will have when wearing it, clinical experience has indicated that certain levels of amputation are incompatible with some tasks, for example, intensive activity is particularly fatiguing to the high thigh or double amputee It is often necessary for an individual to forego returning to his former occupation, either because the site of amputation renders it impossible for him to resume it, or because his efficiency in its performance would be lowered by rapid tiring Here again an understanding of prostheses will give him a sounder basis upon which to build a planned occupational readjustment, if one seems indicated, and the guidance of the surgeon will be of immeasurable value in directing him toward a vocation which will be in accordance with his physical capabilities

As prosthetic training begins, care should be taken to encourage, but not to engender false hope within the patient It should be stressed that the proficient use of the artificial limb, as that of any other mechanical instrument or apparatus, will not be easily acquired It should also be pointed out that there will be a period of adjustment to the new limb in which there will be discomfort, just as would be experienced in putting a pair of shoes on an individual who had gone barefoot all his life The patient should be forewarned of the shrinkage of the stump which makes constant adjustment and fitting necessary for a time, he will not be distressed then by the discomfort of his first limb nor by the period of time necessary to achieve a proper fit and a degree of efficiency in its use He should also be forewarned that no matter how great his perseverance, or how diligent his training, perfection will not necessarily be forthcoming Many lower-extremity amputees will not be able to run, will have difficulty going over rough or inclined terrain, will find it slow and tedious to go up and down stairs, and will be excluded from certain sports and physical activities which require

prolonged or strenuous exertion The individual who has lost an arm will not experience the difficulty in mobility, as does the leg amputee, but will be submitted to a certain amount of frustration during all activities which require bimanual dexterity, and will be forced to change many everyday habits from the major to the minor arm There should be no excessive optimism concerning his achievements or concerning the future developments of prostheses, if he is encouraged in excessive optimism and if too high a goal of achievement is set for him, he will likely become depressed, uncooperative, and antagonistic, and will reflect self-pity and resentment of his affliction If a completely honest picture of the situation is drawn for him and if his training is intelligently planned toward gradual progression, he will gain self-confidence and a tolerance of his disability

The reaction to the actual wearing of the artificial limb varies In the early stages of its use, the primary wish of most amputees is to disguise the deformity and achieve the appearance of normalcy by eliminating the empty coat sleeve or disposing of the crutch Special aids are often employed, such as special tailoring or, with women more particularly, the carrying of some object in the artificial hand such as a purse or handkerchief This camouflage creates a sense of wholeness and balance, and often in the well-adapted amputee will help him to forget the loss of limb As time passes, some few continue to wear the prosthesis for camouflage (this is an economic necessity for those who appear before the public as entertainers, speakers, etc), but to most, function becomes the primary consideration, and the limb of minimal utilitarian value, such as that adapted for shoulder disarticulation, is usually discarded as an encumbrance and an inconvenience

Those who strive and learn to use the prosthesis as a functional tool to replace the limb that is lost often become so accustomed to it that the feeling of loss is almost nonexistent Although the artificial limb will never become a part of the body, it may gain the same inward relationship to the amputee that a pair of skates has to the skater, a golf club to the golfer, or a bat to a baseball player With the well-trained, well-adjusted amputee, this intimate relationship will tend to minimize the artificiality of the prosthesis Certain individuals take great pride in their accomplishments with the artificial limb and become true exhibitionists in demonstrating them

The final period of readjustment comes when the patient returns home and begins to take his place in the normal life of the community His first contacts are with his family and close friends who are inclined to hover over him with indulgence and supercourtesies in an effort to make life easier for him He usually reacts unfavorably to such treatment, since it robs him of his self-sufficiency, and therefore his self-respect, and would much prefer to be accepted naturally and allowed to learn to do for himself Casual acceptance and encouragement toward self-help will do much to further and hasten his reintegration back into the normal family relationship

In his social contacts beyond his family and immediate friends, the amputee faces not only favoritism and solicitude, but also curiosity The reaction to this attitude depends, largely, upon the individual and upon the psychiatric guidance which he has received during hospitalization and convalescence Some few, who remain markedly depressed, react by becoming irritable, dissatisfied, and impatient, and may withdraw into seclusion or drift into the lower stratum of society as their resentment and bitterness increase and their self-respect is drowned in self-pity With them, rehabilitation is a slow and often impossible process Fortunately, this is not the rule Generally among those who have had thoughtful care, there is a tendency in the early stages for the patient to seek the

company of other amputees where the loss of his limb goes unquestioned, and he is treated as a normal individual, later, as self-consciousness subsides and he finds that he is accepted into society, he usually becomes well-integrated in his community, and, because of his achievements, is not the object of pity but is considered a physical and social equal by those with whom he comes in contact

In this final phase of rehabilitation, the achievement of economic security is of primary importance To maintain employment, the amputee must possess the self-sufficiency which comes with a healthy mental attitude, must be able to depend upon his stump and not be subjected to days from the job by frequent breakdown, and must find suitable placement in work which lies within the limits of his experience and his mental and physical capabilities and in which he finds interest and satisfaction When the patient has found the solution to this problem and has become stabilized in his community, his place—as that of any other individual—is determined by his personality and his attitude toward life The extrovert will usually succeed by his cheerfulness and his abundance of interest, and by ignoring his physical limitations by unconsciously living within them, and he will usually do well if he has the determination and perseverance to carry through his training in the use of the limb, and if he has the force to conquer any obstacle that comes before him by whatever adaptations are necessary The introvert, however, may be withdrawn, depressed, and resigned to his fate—often to the extent of apathy Practically all groups will have anxiety which diminishes with time but is usually maintained at a minimal level when livelihood and economic and social freedom are dependent upon the prosthesis

GLOSSARY

The glossary of the amputation surgeon includes such terms as

Final type amputation, or *closed amputation*, is one which is performed in a clean field, and in which skin flaps are closed over the end of the stump by plastic methods

Temporary type amputation, or *open amputation*, is one which is carried out in the infected or potentially infected field and in which the wound is left wide open after the removal of the limb to prevent the further progress of sepsis Such an amputation must always be followed by closure of some type when all signs of infection have subsided The open amputation is sometimes called a "guillotine" amputation This, however, is a misnomer when applied to the modern temporary amputation herein described Up to the time of World War I, there was a surgical procedure of this name in which all tissues were cut at the same level, after the fashion of "La Guillotine," but it has been considered obsolete since then

Primary amputation is the first amputation, and may be either open or closed in type The word "primary" denotes nothing more than the fact that it is the original procedure

Reamputation is merely a second amputation in which the limb is sectioned at a higher level

Minor amputations are those of the foot distal to the tarsometatarsal joints, and those of the hand distal to the carpometacarpal joints

Major amputations are those in all other regions

Site of election is the level at which amputation is ideally performed This is based on the adaptability of the stump to a prosthesis, and on resistance of the stump to the repeated trauma of use

Area of election is that portion of an extremity immediately proximal to the site of election in which the function of the resultant stump is still efficient although not quite as satisfactory as the ideal

Final closure is the covering of the wound left by amputation when no further procedures are anticipated

Primary closure is the closure of the wound immediately following amputation This may be either final or secondary in type

Secondary closure is the temporary closure of an open amputation for the purpose of obtaining early healing and of minimizing painful dressings and prolonged convalescence in bed It can be done as soon as the granulation tissues are normal and there is no evidence of deep infection, usually from seven to ten days after amputation

Plastic repair is the plastic rearrangement of the skin and soft tissues of the amputation stump to eliminate scarring, ulceration, redundancy, dog-ears, etc

Revision is the plastic rearrangement of the skin and soft tissues of the amputation stump accompanied by the excision of a minimal amount of bone in order that closure of the wound may be effected

PART 2

SURGICAL CONSIDERATIONS

II. WOUND HEALING AND SURGICAL CARE OF THE INDIVIDUAL TISSUES

A distinctive feature of amputation surgery is that it is not aimed solely toward the saving of life or the improvement of the comfort and health of the individual, but is directed also toward the creation of a stump which will be useful and comfortable within a prosthesis, or functional and cosmetic in itself if the use of an artificial member is not anticipated. Actually, therefore, the criterion for amputation surgery is the stump. The ideal stump has been defined previously in this text, but let it be said again here that it should be healthy, functional, and able to withstand the trauma of use. More specifically, it should be of a length best adapted to a prosthesis and should be formed to fit evenly within the socket of the artificial limb (if no prosthesis is to be worn, its length and form should be that which will best meet the cosmetic and functional requirements), it must be free from pain and contractures, it must be formed throughout of healthy tissues which possess normal blood supply and sensation, and its surgical scar must be thin and linear, and must fall where it will be least subject to irritation. This is the ideal, not always will circumstances permit its attainment. Frequently, perfection of length and shape must be sacrificed, but the requirements of good blood supply, healthy tissues, and sound healing must be met, for tissue slough and wound breakdown may result in eventual loss of valuable length, or any number of complications which may destroy the usefulness of the part. It is evident that the amputation surgeon must possess a thorough understanding of the principles of wound healing and a ready knowledge of the peculiar characteristics of the individual tissues involved and the treatment which should be accorded them. This section will present these considerations, with special emphasis upon the influencing factors peculiar to amputation surgery, such as the time element, the level of severance, the type of amputation (open or closed), and the specific use of the tissues.

WOUND HEALING

There are many general factors which influence wound healing. Of these, age is most important in amputation surgery, where many structures are involved and where plastic rearrangement of the tissues is usually necessary. In

childhood and in young adulthood the potentiality for tissue repair is great, wounds heal rapidly, and extensive plastic procedures can be carried out with maximal success In contrast, in the aged, tissues have poorer circulation, elasticity of the skin is lost, resistance to secondary infection is minimal, and, not infrequently, poor dietary habits have led to malnutrition Thus it is apparent that amputation in the higher age brackets, especially that demanding extensive plastic rearrangement, should be approached with caution As to the other general factors, there are certain conditions, such as hypoproteinemia, dehydration, focal infection, general systemic disease, and circulatory failure, which have been found to retard wound healing very definitely Ideally the patient should be checked for any such conditions, and measures should be taken to correct, or at least control, them before surgery is undertaken Unfortunately, there are some circumstances imposed by the need for amputation which do not permit of the opportunity to carry out these measures

It is here that the *time element* enters into the picture dividing amputations roughly into three groups

(1) those which must be performed immediately despite the general condition of the patient,

(2) those which must be performed early, with time only to prepare the patient to withstand surgery, and

(3) those which may be delayed until the factors which retard wound healing can be corrected

In the first group are the amputations performed to free an individual who has been pinioned beneath an immovable object, and those necessitated by the presence of severe uncontrolled infection The classic example of the latter is acute, fulminating, rapidly ascending gas sepsis, where the gas can be seen to be inching its way upward over the course of minutes and the alternative to immediate amputation would be certain death In the second group, the early amputations, are those performed to remove a severely mutilated or crushed extremity or one invaded by malignant tumor or by uncontrolled infection which is not immediately endangering life Such a limb should be removed without undue delay because of the profound effect it may have upon the patient, but there is time for the administration of supportive measures, such as shock therapy and treatment of associated injuries, so that he may be more adequately fitted to withstand surgery In the third group, the delayed amputations, are those which are performed for the purpose of removing an extremity made useless by controlled infection, vascular disease, massive benign tumor, or less mutilating injury with or without gangrene Also in this group fall the final closure of open amputations (plastic repair, revision, or reamputation), and elective amputations such as the removal of a supernumerary toe, a hopelessly deformed foot, or a part rendered useless through old infection In all of these circumstances surgery can be carried out at the convenience of the patient and the surgeon, and plenty of time can be allowed to create ideal conditions for the promotion of wound healing

In all fields of surgery the local factors which are most detrimental to wound healing are hematoma, infection, and separation of the wound edges, and by inverse reasoning, those which aid wound healing are skillful handling of the tissues during surgery, avoidance of all conditions which activate infection, and closure by accurate approximation of normal tissues

Let us first consider **hematoma,** for it is one of the most common causes of wound breakdown When blood oozes from the cut surfaces of the tran-

sected tissues, it builds up pressure and forms a pool in dead space or forces its way into the tissues or through the suture line It is evident that any such pressure behind the lips of the wound will prevent it from healing In addition, the pools of hemorrhagic ooze form an ideal pabulum for possible pathogenic organisms The most effective preventive measure which can be taken against hematoma is meticulous hemostasis at the time of operation, through the use of ligature, electrocoagulation, and fibrin foam and its equivalents Two additional precautions which may be taken at the time the wound is dressed are the use of a drain to obviate fluid accumulations, and the use of the pressure dressing to diminish the dead space

Infection is exceedingly destructive in the amputation stump, for it means edema and congestion of the soft tissues with local necrosis and the eventual loss of skin cover, and frequently loss of valuable length Wound closure should never be effected in the presence of active infection, and utmost care should always be taken to avoid all conditions which would foster the growth of latent sepsis Pathogenic bacteria will thrive in the ideal culture media provided by the amputation wound if blood supply is poor, or if any necrotic, edematous, devitalized tissues and organic foreign bodies are present It is incumbent upon the surgeon, therefore, to débride the wound of all necrotic elements to the point where the tissues are viable and bleeding is normal, to handle them gently to avoid traumatization, and to eliminate any foreign matter In this last respect, a word should be said concerning the silk and cotton suture, which, being of organic and vegetable origin, frequently become a nidus of bacterial activity Although they have a past record of excellence in the clean surgical wound, they cannot be tolerated in potentially infected fields, and on this basis are excluded from the larger share of amputation surgery An additional precautionary step which should be taken against infection is the administration of chemotherapy Local chemotherapy is neither necessary nor desirable, for it has been proved that no available antibacterial agent can sterilize a wound (in fact, the presence of these drugs tends to evoke further exudation of the tissues and delay healing), but systemic administration is another matter Penicillin is the drug of choice and is an effective agent against all but a few resistant strains of invasive organisms Sulfonamides are effective only in those wounds which are infested with hemolytic streptococci

The **separation of the edges of the wound** is usually the direct result of inaccurate approximation of the tissues, improper suturing or placement of a drain, or excessive postoperative movement It may occur, however, when hematoma forms behind the suture line, or when infection arises within the wound so that the tissues become edematous or necrotic and blood supply is impaired It is best avoided by approximating the wound edges accurately so that there will be no inversion or infolding of the skin, by placing the sutures with care, and by providing postoperative tissue rest so that edema will be minimal and blood supply good, and the reparative processes may take place without interruption The placement of the sutures and drain deserves a word or two of comment Sutures should not include large masses of tissue, nor should they be drawn tightly so that the skin is under tension, for in either instance blood supply will be hindered and ischemic necrosis will result, stay sutures should be avoided because of the frequency with which reaction occurs about them (they should not be necessary in any event, since tension implies a lack of adequate skin covering) If a drain is used, it should be placed between the first and second, or second and third sutures, never at the end of the incision, and should not be left any longer than is necessary

In view of the profound importance of the *condition of the surgical field* in wound healing, and of the influence which sound healing subsequently has upon the future utility of the amputation stump, choice of the level of amputation and the decision for open or closed technique take on added significance For the level of amputation dictates the area within which surgery is to be performed, and thereby the condition of the tissues which are to be used, and the choice of open or closed technique determines the manner in which the tissues are to be handled and the time at which wound closure is to be effected

The ideal *levels of amputation*, or the sites of election, as they are called, are those points within an extremity through which, experience has proved, amputation can be performed most successfully from the standpoint of the functional stump For the sake of the future utility of the stump, severance should always be carried out at these levels, or as close to them, proximally, as is possible In elective amputations the site of election will always present a clean surgical field, and definitive surgery and wound closure may safely be effected Upon occasion, contracture or fibrotic tissues may be present due to past infection or injury, and may necessitate the use of special plastic procedures, if, in the opinion of the surgeon, such procedures will not impair the usefulness of the stump, amputation should be performed and closure effected at that level regardless In amputation, the etiology of which is recent severe trauma or sepsis, the site of election may fall within an area in which tissues are traumatized or infected, or at best potentially infected It is in such cases that the clinical judgment of the surgeon is taxed, for he must determine to the best of his ability whether or not sufficient healthy tissues will remain at that level for the creation of a good stump when débridement, treatment for infection, and tissue rest have been carried out If he so judges, amputation should be performed within the site of election rather than at a higher level, despite the condition of the surgical field

Since the level of amputation frequently imposes an infected surgical field, and the time element often prohibits the delay necessary to restore the tissues to normal, it becomes apparent that the amputation wound cannot in every instance be closed immediately, if the dictates of sound wound healing are to be followed Therefore, the surgeon must ascertain the degree of contamination of the structures and make his decision for open or closed amputation accordingly If the field is grossly contaminated, or actually infected, sepsis should be controlled through wide-open drainage, removal of necrotic tissue, and the elimination of dead space by the *open amputation technique*, and final closure should be deferred until the tissues have returned to a normal, healthy state When the contamination of the wound is minimal, and the tissues are not severely traumatized, as in those made by a piece of glass or a knife, final, *closed amputation* may be performed

(1) if not more than eight hours has elapsed since the time of injury, and

(2) if it is not necessary to mobilize the skin extensively to effect closure without loss of bone length

In case of doubt, the wiser course is to use the open technique and undertake definitive surgery at a later date When the operative field is clean, as in elective amputation or that indicated by infection or trauma remote from the site of election, or when time may be taken before severance to allow the tissues to return to normal, closed amputation is routinely performed

THE SURGICAL CARE OF THE INDIVIDUAL TISSUES OF THE AMPUTATION STUMP

Since amputation surgery is cross-section surgery, it involves many structures, each of which contributes to the eventual form and usefulness of the stump The following pages are devoted to a discussion of the individual characteristics of these structures, with particular reference to their treatment in amputation surgery

Skin

The skin is the most important structure for it forms the covering for the amputation stump and is used to effect closure of the amputation wound When final repair of an open amputation is performed, or primary closed amputation carried out, the skin of the distal portion of the stump is fashioned into flaps, which are approximated to close the wound and form covering for the bone end In the case of the open amputation, skin traction is applied following the initial surgery to insure adequate skin length for this procedure Rarely are skin grafts used in amputation surgery, and then only under certain circumstances

Since the skin of the amputation stump is subject to the trauma of use and in most instances, pressure from the prosthesis, there are certain **specifications** which it must meet Throughout the stump it should possess normal blood supply and sensation and should be free from binding scar and dermatologic affections That which is to close the wound and cover the stump end should, in addition, be mobile in order that its plastic rearrangement may be carried out without traumatization, should be of adequate length in order that it may be sutured without tension and heal with thin, linear scar, and should have sufficient subcutaneous fat to form padding for the bone end Before the flaps are planned, the skin should be inspected carefully with these specifications in mind

If the skin appears to have inadequate *circulation,* as evidenced by coolness, cyanosis, or a dusky red color, it should not be employed to form the skin flaps, or if it must be used in order to achieve a stump of sufficient length, closure should be delayed until the blood supply is normal, in order to insure wound healing and avoid the loss of valuable skin length because of tissue slough By the same reasoning, skin in which there is extensive scarring, adhesions, or subcutaneous fibrosis should not be included in the flaps and should be avoided in planning incisions, for these conditions form circulatory barriers Such areas, however, do not require special surgical treatment unless they bind the skin fixedly to underlying structures, and thus form a tension point which may break down with use of the limb In that event they should be excised and plastic closure should be carried out

If the skin of the amputation stump does not possess normal *sensation,* it will be subject to trophic changes and ulceration and will be exceedingly susceptible to mechanical and thermal injury The flaps should always be planned so that their bases lie in a general line with the incoming sensory nerve supply, and secondary incisions should never be placed where they will interfere with sensation When there is extensive skin loss, these rules are sometimes difficult to abide by, but they are none the less important In such instances, atypical flaps are usually necessary and special care must be taken to insure that the sensory nerves are not severed by the incision Occasionally, skin grafts are used in final surgery to replace lost skin and close the amputation wound in such cases This is a useless procedure when the graft will lie in an area which will be subject to pressure or weight-bearing, for grafted skin is asensitive and will break down under these circumstances, and ulceration and sloughing will ensue

Edema, the signpost of latent infection, and all *dermatologic affections*, such as folliculitis, furunculosis, and cutaneous abscess, are incompatible with sound wound healing and should be completely eliminated from the skin before final surgery is undertaken Adhesive tape should not be used upon the amputation stump, for it irritates the skin, particularly in the presence of drainage from the wound Rather, the elastic type of bandage generally used for compression should be employed to hold any dressings in place If this is not practical, moleskin or adhesive elastic bandage may be used but the site of application should be watched for signs of inflammation, and if any such appear, the dressing should be fixed by Scotch tape This should not be applied over the inflamed area but should be placed on normal skin

Skin of ideal *mobility and subcutaneous padding* is not always available for flaps in every amputation, for the structure of the skin varies in different parts of the body, and texture and quality vary with the type of individual and with age In the different parts of the body the skin is suited to the function which it is required to perform That of the palms of the hands, soles of the feet, and the gluteal region is thick and bound down tightly by deep fascial bands to the underlying structures so that it is ideally adapted to pressure and weight-bearing, it lends itself poorly to mobilization, and liberal allowance for length must be made when shifting it in wound closure and plastic procedures The skin over the joints, particularly on the flexor surfaces, is thin and poorly nourished, it contains a large number of elastic fibers, and is therefore well suited for the wide excursion of gliding motion required of it When wound closure is to be effected in regions with this type of skin, it should be remembered that circulation is usually poor, skin retraction is great, and scar and keloid formation is maximal Between these two extremes is the skin overlying the shafts of the long bones, which is fairly mobile, has subcutaneous padding and good blood supply, and, because of these qualities, affords freedom and protection, when its use is required in wound closure, it reacts well to mobilization and heals with minimal scar As to the variations in texture and quality of the skin in the different types of individuals and in the different age groups, it can be noted, for example, that the skin of the redhead and the tall, thin, asthenic type is thinner, with less subcutaneous padding and with poorer circulation, than is that of the dark, swarthy type, and the skin of those in the older age groups is less well nourished, has poorer tone, and is less elastic than that of the younger individuals In planning the skin flaps, these variations should be taken into account

(1) if less than normal mobility is present, extensive plastic rearrangement should not be projected,

(2) if excessive retraction can be anticipated, liberal allowance for length should be made,

(3) if broad, keloidal cicatrix can be expected, the flaps should be planned so that the scar will fall well away from any possible pressure area,

(4) if there is a minimum of subcutaneous fat, a layer of fascia should always be included in the flap in order that the bone end may have adequate padding

Length is of equal importance to the other specifications of the skin flaps It should be such that the skin can be sewn under normal tension If it is too tight, the suture line will tend to break down due to avascularity and tension, if it is too loose, the redundant folds of skin will be subject to circulatory stasis

and edema, and their flabby mass will fit poorly within a prosthesis In rare instances in the upper extremity when greater stump length has been needed to improve function, this redundant skin, if normal, has been put to good advantage by inserting a bone graft within it Such a procedure, however, is limited in its application and is attended by considerable risk, it should, therefore, only be considered where the need is great and the circumstances are ideal Only in children is the stump purposely planned with some redundant skin There, there is a tendency for the rate of growth of the bone to exceed that of the skin, and a greater allowance should be made for skin if it is not to become stretched taut over the bone end

Generally speaking, short flaps are to be preferred to long ones, for the shorter the flap, the better the circulation Under normal circumstances the incision starts at or immediately above the bone level, and the flaps are fashioned so that their combined length is equal to the anteroposterior diameter of the limb at that point Ideally, they are planned on the following basis

(a) **In the upper extremity**

(1) All amputations above the level of the wrist utilize anterior and posterior skin flaps of equal length This places the scar terminally where it will not receive pressure when the prosthesis is worn, since only the sides of the stump are in contact with the socket

(2) Amputations from the level of the wrist distalward utilize long anterior and short posterior flaps, so that the end of the stump is protected by thick, tough palmar skin

(b) **In the lower extremity**

(1) In amputations about the hip, the raquet incision with a long posterior medial flap is the procedure of choice Here the suture line falls anteriorly and laterally to keep it well away from the weight-bearing area of the ischial tuberosity and gluteus maximus, and to protect it from fecal contamination during the phase of healing

(2) In amputations of the thigh, I prefer an anterior flap one inch longer than the posterior flap, so that the suture line will fall well above the bone end Others prefer flaps of equal length, so that the suture line falls immediately behind the bone end

(3) In end-bearing amputations of the distal end of the femur, long anterior and short posterior skin flaps are used, so that the suture line, which lies well posterior and above the weight-bearing area, will not be subjected to pressure as weight is carried on the end of the stump

(4) In amputations of the leg below the knee, I prefer an anterior flap about one-half inch longer than the posterior flap, in order that the suture line will fall well posterior to the bone end Some prefer skin flaps of equal length, which allows the suture line to fall immediately behind the bone end

(5) In the Syme amputation, where the weight is carried on the distal end of the tibia, a long posterior heel flap of plantar skin is used The scar falls anteriorly, well above the weight-bearing area

(c) **Atypical flaps**

Although the conventional flaps are desirable, valuable bone length should not be sacrificed in order to obtain them, whenever plastic rearrangement of the skin can be carried out in such a manner as to form a satisfactory stump, with minimal loss of length. This often leads to the formation of long, atypical skin flaps. Here, it is preferable that the base of the flap be formed so that its blood and sensory supply are normal. In very long flaps where the circulation is in doubt, it is desirable to delay the flap to insure adequate circulation (i.e., outline the flap and lift it from its bed and then resuture it in its original position). When a long flap is placed around the end of a stump, care should be taken not to overstretch or kink it, and pressure dressings should be applied with special care, in order that the blood supply will not be endangered. There is another factor which must be considered in relation to a long flap used in this manner, that is, the extent to which tailoring should be carried out. If the flap is simply folded over the end of the stump and its sides sutured together, "dog ears" will appear at the distal ends of the suture lines on either side of the stump. In order to avert this and give a smoothly rounded shape to the skin covering, deep, V-shaped wedges of skin would have to be removed from either side of the flap at the point where it folds over the stump end. If the reader would take a piece of paper and double it over loosely, as the flap is folded, and then cut wedges from it until the end was rounded on two planes, he would find that almost a third of the width of the paper had been removed. It is readily seen that this situation, when applied to the long skin flap, might well jeopardize the circulation of its distal end. It is well, if the circulation is questionable, to allow the "dog ears" to form, and to remove them, when the wound has healed, by eliptical incision and simple side-to-side closure.

There are **two specific points relative to the surgical technique** in forming the flaps, which should be noted here:

(1) the raw surface of the skin flap should always be covered by a moist saline sponge at the time of surgery, and

(2) the skin should be separated from the underlying structures only to the extent which is necessary for proper wound closure, extensive subcutaneous dissection and mobilization being avoided in so far as is possible.

Skin grafts should be used in amputation surgery only under certain circumstances:

(1) in the open amputation, where traction is not to be used, and

(2) in the closed procedure, only in those areas which will not be subject to pressure or weight-bearing.

In most cases in open amputation, skin traction is necessary if adequate skin length is to be obtained for wound closure. It cannot be effectual in the presence of a skin graft, for the scar which forms about the periphery of the graft firmly binds the normal skin and creates an effective barrier to its downward progression. When a graft has been employed as temporary covering for the amputation wound, it must be excised, together with the circumferential cicatrix about its border, before traction can be applied. Usually, the only places where skin grafts are permissible in open amputation are on the stump severed well below the ideal level where skin length is unquestionably adequate for future repair.

without the intervention of traction, and in the hand or foot where, due to the nature of the skin, traction is notoriously ineffective, and would not be applied in any event In the closed amputation grafted skin on pressure or weight-bearing areas in the stump is absolutely contraindicated, for no matter what the type, free split or full thickness, tube or flap graft, and no matter how great the technical excellence of the procedure, the result is uniform failure, for sensation is lacking and the skin of the graft will break down, with ulceration and trophic disturbances, under minimal pressure or tension from the prosthesis This is equally true of skin grafts on any part of the body which might be subject to pressure from the proximal harness of the artificial limb There are instances, however, such as in amputations about the hip, where skin grafts can be placed on extensively denuded areas, or can be used partially for wound closure, if it is assured that they are well away from any pressure or weight-bearing point

Muscle

The muscles within an amputation stump serve the dual functions of activation and padding During operation, the activating muscles are seldom visualized, and at that time the surgeon's concern is only with those which cushion the circumference of the bone The surgical objectives in the treatment of the muscles are to provide adequate circumferential padding for the bone to protect it from the firm, unyielding pressure of the prosthesis, and to give the stump a gently tapered contour, so that it may be well adapted to the socket of the artificial limb It should be stressed here that muscle is used to supply padding for the circumference of the distal end of the bone, and *not* for the sectioned surface

This is in contrast to the treatment of muscle in amputations before the scientific studies of the last few decades, and before the advent of the modern prostheses *In the past,* the stump was allowed to form with large redundant masses of muscle over its distal end The factors responsible for this were

(1) the type of prosthesis then used, and the circumstances attendant to amputation surgery, and

(2) the belief in two premises—

(a) that a thick layer of muscle formed an excellent padding for the sectioned bone end, and

(b) that circulation was better afforded to the end of the stump when it was covered by muscle

In the era of the "peg leg" all lower extremity stumps were end-bearing, regardless of level, and a prosthesis was seldom used on an upper extremity stump, bandaging was unknown, sepsis was the rule, and wounds seldom healed by first intention, but closed gradually by invaginated scar, which extended to the bone An overhanging layer of soft tissue presented no fitting problem and was considered necessary to protect the unsound cicatrix *Today,* with improved surgical techniques and the great advances in the prosthetic field, the stumps and prostheses of the lower extremity are only planned for end-bearing at those levels of amputation which present a broad, flat, bony surface, which can be covered with tough, weight-bearing skin, and which, as a consequence, requires no thick padding, all others are designed for proximal bearing, and the proximal bearing stumps of the lower extremity and all stumps of the upper extremity are tapered to fit comfortably within the socket of the artificial limb As to the belief in the desirability of muscle as padding for the bone end, the two premises on which it was based have since been proved false Experience has shown that

muscle is not constituted for weight-bearing, and reacts to pressure by fibrosis and scar tissue replacement It, therefore, forms a scar tissue barrier which impairs, rather than improves, the blood supply, and causes stasis and dependent edema in the dependent muscle and skin In one or two modern amputation procedures, where the stump is not planned for end-bearing and excessive muscle retraction would otherwise be inevitable, a very thin muscle flap (not exceeding one-fourth inch) is used, but thick muscle flaps are definitely contraindicated, and large muscle masses over the stump end cannot be tolerated Not only do they form fibrotic circulatory barriers, but they fit poorly within a prosthesis, are frequently subject to weeping and abrasions, and are the cause of general discomfort I wish to stress this particularly in reference to the stump in which peripheral vascular disease is present There the circulation in the skin is always superior to that in the deeper tissues, and the presence of large muscle masses, with marginal circulation, beneath the skin is most undesirable, for it courts further embarrassment of blood supply

At operation, the muscles are cut so that after retraction they will fall at the level of the saw line Section is carried out slowly, so that the surgeon may equalize the difference in retraction of the different muscle groups, which varies with the length and normal excursion of the muscles (It should be mentioned here that retraction is usually less in the aged, because of poor muscle tone and nutrition, and will be slight or absent where the muscle has undergone extensive fibrosis) When the muscle is cut too short, it retracts above the bone level, and the distal circumference of the bone is then covered by skin alone Such bone, without circumferential padding, does not form a satisfactory lever and is often painful on use If the muscle is cut too long, a redundant soft tissue mass remains which fits poorly in a prosthesis and is often subject to breakdown After section is complete, any excess of muscle beyond that needed for padding the sides of the bone may be removed by skiving and the resection of muscle wedges (myoplasty) to improve the general shape of the stump for adaptation to the prosthesis Opposing muscle groups should not be sewn to one another over the bone end, for this may result in movement which in turn may cause bursal formation over the bone end, and pain due to tension on nerve endings

Tendons

Tendons add little to the shape or durability of the stump, and the circulation within them is poor For this reason they are not generally used as covering for the bone end In closed amputations they are usually sectioned near their muscular attachments and removed, in open amputations they are cut so that they will not retract above the wound edge, lest in so doing they cause the upward dissemination of infected materials The exceptions to this are the broad, flat, well-nourished tendons of the quadriceps femoris and triceps humerus muscles, which are sometimes sutured over the end of the bone in the tendoplastic amputations near the distal end of the femur and of the humerus

Fascia

In the **primary closed amputation,** fascial flaps are used to effect the grouping of the muscles about the sides of the bone, and to afford a base for the insertion of the freshly transected muscles so that they will not retract at a later date In addition, the fascia thus used serves to prevent adhesions between skin and bone It is usually cut in the same pattern as the skin flaps, and, to insure better circulation, the two structures are not separated In certain instances, such as the below-knee amputation, fascia is fashioned in a single long

flap and some subcutaneous dissection must, of course, be carried out In the occasional closed amputation case where the fascial flap is omitted, the muscles will usually retract over a period of several months, and the unprotected bone will protrude beyond them

In the **final repair of the open amputation** the muscles have already become fixed about the bone by scar tissue and the fascial flap is omitted

Nerves

The treatment of nerves is directed toward the elimination of pain Pain has its genesis in scar which may be either intraneural or extraneural in type Once scar has become established, it may affect the nerve either through mechanical tugging and pulling upon the sensitive nerve end, or by strangulation of the nerve in scar tissue The response to this is manifested in local, regional, or phantom limb pain In the first instance, local pain, the irritation of the nerve bulb alone is responsible, in the second, the neuroma is usually imbedded in scar which extends outward to the neighboring tissues, and any transmitted motion is reflected in the nerve ending as regional pain, in the phantom limb type of pain, excitation of the nerve end is transmitted to the brain, which refers the pain to the amputated portion of the extremity below the end of the stump (Note Only a small percentage of true phantom limb pain is on the basis of peripheral stimulation)

Since every severed nerve forms a neuroma at its distal end in the physiologic attempt at repair, this response is not preventable However, the involvement of the neuroma and its outgrowing axis cylinders in scar is avoidable to a large extent through the gentle handling of the nerve and its investing soft tissue, the avoidance of chemical irritants, and the placement of the nerve in a bed of normal soft tissue free from cicatrix

In **open amputation,** nerves are isolated, pulled gently downward, and sectioned by the clean cut of a sharp knife so that they will fall about one-half inch above the open surface of the wound If a nerve is left longer, it may become strangulated by the scar tissue which forms in the wake of the surface granulations, or the exposed end of the nerve may be very painful when the wound is dressed or the stump is subject to manipulation If a nerve is cut at a higher level, it will retract upward for a considerable distance above the surface of the wound When this occurs, a channel is created up which infection may spread, and the nerve rests at a point where it is difficult to find when the final repair of the stump is carried out

In the **closed amputation,** the treatment of the nerves is simplicity itself Each nerve is isolated in its bed by careful dissection, drawn gently downward, severed by the clean cut of a sharp knife, and allowed to retract upward so that its distal end lies an inch or more above the cut surface of the muscle The bed in which the nerve end lies following retraction should be carefully inspected to see that no scar is present and that the tissues are normal

In either type of amputation, the use of a ligature near the end of the large nerves is helpful in controlling intraneural hemorrhage, and the injection of 2 per cent Novocain in the major nerves of the upper arm and thigh is of distinct value in the prevention of shock I have performed the section of the sciatic nerve in a number of cases with such an injection, and in a number of cases without it, and have found that the fall in blood pressure, which is an almost constant accompaniment of handling this nerve in its upper levels, is greatly decreased when this drug is used

Gentle handling throughout is the primary factor in the treatment of nerves Any roughness may affect the nerve for several inches above its end, and any strong pulling and tugging may damage the delicate intraneural structure by tearing the minute nerve bundles and causing small areas of hemorrhage, which will be replaced by scar The simplest treatment seems to be the most effective in avoiding such trauma and insuring minimal scar formation Many complicated methods, such as the electrosurgical cutting unit, have been suggested for nerve division, and although there is no objection to some of them, they are less practical and have no advantage over the clean stroke of a sharp knife Similarly, in an effort to reduce the frequency of painful neuromata, various plastic procedures have been tried, such as the nerve wedge of Ritter, the perineural flap of Bier, turning the nerve back upon itself and suturing it in a hole in the perineurium, as described by Bardenheuer, and implantation of the nerve within muscle or bone, but these methods have become obsolete, for they have proved no more effective in the elimination of the sequelae of nerve section than the simple procedures described above The injection of absolute alcohol and other solutions in the nerve end has also been used to prevent neuromata, but has proved of no particular value, in fact, these irritating and sclerosing solutions have been thought by many to enhance the possibilities of painful neuromata

Periosteum and Bone

Next in importance to good skin covering is the **bone length** of the stump Ideally, the level at which the bone is sectioned will fall within the areas of election i e, those sites which experience has proved result in the most satisfactory stump length from the functional standpoint, without a prosthesis in the case of the minor amputations, and with a prosthesis in the case of the major ones Within these regions, the greatest possible length should be maintained provided adequate soft tissue covering is present

In the **closed type of amputation,** the periosteum is divided by sharp dissection near the bone level It is reflected downward with a periosteal elevator to expose the underlying bone, which is sectioned immediately distal to the incision Meticulous care should be taken to preserve the periosteal attachments of the muscle to the bone, since this will aid in maintaining muscle grouping about the bone end and will minimize periosteal bony reaction The bone is divided transversely to its longitudinal axis in all but end-bearing amputations There it is divided in such a manner that the end of the sectioned bone would lie parallel to the ground if the patient were in the standing position During osteotomy the limb should be well supported and sawing should proceed slowly as bone section nears completion, so that splintering will not occur and result in an uneven bony cross section and the implantation of tiny bone fragments in the soft tissues Following division of the bone, all sharp or projecting bony prominences are removed, and the bone is smoothed with rasp or file All bone dust is then irrigated from the wound with normal saline, for these tiny osseous fragments may become the basis of bony proliferation if allowed to remain within the wound The medullary canal requires no special treatment ordinary bleeding can usually be controlled by pressure or, if necessary, by a tab of muscle or a piece of fibrin foam, bleeding resulting from the severance of a nutrient vessel is sometimes more easily checked by placing a small hemostat in the nutrient foramen The medullary canal should never be curetted, because this practice both creates dead space at the end of the bone and impairs the circulation to the distal cortex

In **open amputation,** the periosteum is incised circumferentially and the bone is divided transversely at the same level All periosteal remnants are trimmed away, to minimize the danger of excessive callus formation No attempt is made to smooth or shape the bone end

An **aperiosteal technique,** in which a quarter-inch cuff of periosteum is removed from the bone end following osteotomy, was originated by Bunge to minimize bony proliferation It may be used in closed amputations as an alternate method to that described above, but it creates greater disturbance about the bone remaining in the stump It should never be employed in open amputations where the possibility of occlusion of the vessels of the medullary canal by septic thrombosis is always present, for there the extramedullary as well as the intramedullary blood supply to the cortex of the bone end would be lost, and the bone would die, resulting in a terminal area of necrosis known as a "ring sequestrum"

In the course of normal healing, **the medullary canal** becomes occluded by either scar or bone Immediately after surgery it is filled by hematoma, which is gradually replaced by granulation tissue This may continue in its normal transition to fibrous tissue and form a plug of scar, or it may be converted to osteoid tissue and eventually to bone In the latter instance, all prerequisites for ossification are present

(1) blood supply is abundant,
(2) the hematoma forms an ossifiable medium,
(3) osteoblastic cells are present, and
(4) a supply of calcium is available from local rarefaction of bone, from the tiny particles of bone dust which may be left behind, and from the general circulation

Ossification may also occur at the outer margins of the sectioned bone Here it is undesirable, for it takes the form of **osteophytes,** which may exert painful pressure on overlying tissues when the stump is used Such osteophytes are formed through reactivation of the periosteal osteoblasts, and their extent and type are dependent upon the amount of surgical trauma and stripping of the periosteum, the extent of local irritation through sepsis (in open amputation), and the capacity of the tissue for bone regeneration

Over a period of years the bone undergoes a constant remodeling process in accordance with the law of functional adaptation (Wolf's Law) to reach its final form Ideally, the bone will be smoothly rounded at its edges, well padded by muscle at its sides, and covered, without tension or adhesions in accordance with the surgical procedure followed

(1) by tendon in the case of the tendoplasty,
(2) by a thin layer of muscle and fascia in the below-knee amputation, as described by Kirk,
(3) by bone in the Gritti-Stokes procedure,
(4) by fascia in other closed amputations, and
(5) in every instance by freely movable skin

A word should be said concerning the treatment of the bone in **below-knee amputations in children,** where there is a tendency for the fibula to overgrow the tibia following amputation Although both epiphyseal arrest of the fibula and synostosis of the ends of the tibia and fibula have been suggested as preventive measures, I feel that high section of the fibula is adequate as a routine procedure in most instances

Cartilage

The articular surface of joints is formed by hyaline cartilage This highly differentiated cartilage is composed of collagenous fibers, containing cartilage cells and a ground substance While the microscopic detail of cartilage is unimportant in the present discussion, it is worth while to note that it possesses no blood vessels in its matrix, but rather is nourished from the underlying subchondral bone, the synovial fluid, and the adjacent synovia For this reason its response to injury or infection is poor In open disarticulations, where the cartilagenous surfaces have been exposed to severe, uncontrolled, invasive infection, it is well to leave the cartilage to act as a barrier to the upward spread of sepsis into the medullary canal Under these circumstances, the destruction of cartilage is rapid and it is either absorbed by granulation tissue or is sloughed off from the underlying bone In the latter instance it may appear as sequestra or partially sloughed dead remnants within the wound The sequestra and remnants deter healing and should be removed as rapidly as possible In closed disarticulation, degeneration of cartilage is less rapid and is due to change in the character of the synovium, and the loss of the stimulus of motion The cartilage at first becomes dull, granular, and fibrillated, and later is gradually invaded by granulation tissue It is usually the practice to leave the cartilage in major closed disarticulations but to remove it in minor ones In the latter instance, excision, which is carried to the subchondral level, is performed rather because it creates a more shapely stump than because of the degenerative changes which might follow if it were allowed to remain

Synovia

The **synovial membrane** lining the joints is important in amputation surgery because of the synovial fluid which it forms and which may fill the amputation wound Once disarticulation has been performed, or amputation at levels lying within the synovial membrane, the output of this fluid may be less than normal, or it may be increased Frequently in closed amputations it is sufficient to cause a collection of fluid which will break down the suture line, in other instances it may lead to the formation of a bursa which may destroy the even contour of the end of the stump, or be painful when the stump is used For this reason it is good practice in closed amputations to excise all synovial tissue, particularly of the areolar type In open amputations a collection of fluid cannot occur postoperatively because of the presence of wide open drainage, and the future closure of the wound is not endangered because the membrane becomes so infiltrated by scar tissue that its capacity for the production of synovial fluid is lost It is a safe and desirable measure, therefore, to leave the synovial membrane in open amputations so that it may act as a barrier to the upward spread of infection

The Blood Vessels

Careful hemostasis is a basic requirement of amputation surgery and should be accomplished before release of the tourniquet if one is used, or before section of the vessels if a tourniquet is not being used The major vessels should never be ligated en masse, for this endangers the security of the ligature, but should be individually isolated, clamped, and doubly ligated with No 2 plain catgut (Chromic catgut, silk, cotton, linen, or wire is not necessary) If these vessels are well secured at the time of surgery, secondary hemorrhage from them will rarely occur The smaller vessels are usually treated either by simple ligation

with fine catgut or by electrocoagulation, but in open amputations through an actually infected area, the vessels will be extremely fragile and a needle should be used to pass the ligature about the vessel, and special care should be taken in tightening the suture In spite of the most diligent hemostasis, some hemorrhagic ooze may arise from the tiny vessels lying in the cross section of the transected muscle This can be controlled only by a compression dressing and the use of a drain Bleeding from bone is not always preventable and, when it occurs, can usually be checked by pressure If this is ineffective, a muscle tab or fibrin foam may be used, or, in extreme cases, the bony canal in which the vessel runs may be collapsed, bone wax should never be employed

The use of a tourniquet during surgery is of inestimable value to the surgeon by providing a clear, bloodless field in which to work, and to the patient by saving blood at operation The tourniquet should always be used when the limb segment is long enough to apply it, the one exception to this rule being amputation for peripheral vascular disease, where there is a danger of damaging the already inadequate blood supply Fortunately in this instance, bleeding is minimal due to the pathological changes within the vessels

III. SURGICAL PREPARATION

In the period prior to operation the patient is brought to as ideal a state of health as time and surgical judgment permit General disease, toxicity, malnutrition, blood loss, and dehydration are brought under control in order that he may withstand surgery better Fluid balance and blood levels are restored, and preparation is made to maintain them at operation by having plasma and blood available Anesthesia is carefully selected in accordance with the patient's age and physical status, and its administration supervised by a competent anesthetist In all infected, or potentially infected, cases, preoperative and postoperative penicillin is administered to minimize the danger of septic complications Tetanus antitoxin or toxoid is routinely used in traumatic, posttraumatic, or gangrenous cases

In all **delayed and elective cases,** a twenty-four hour sterile orthopaedic preparation is carried out with the objective of eliminating as much of the surface infection as possible The extremity is carefully shaved to a point well above the intended amputation level

(1) in amputations of the thigh this is carried above the level of the iliac crest and includes the pubic hair,

(2) in high amputations of the upper extremity it includes the entire shoulder girdle and axilla

If open granulating wounds are present, the hair should be removed to the level of the wound edge When shaving is complete, the limb is thoroughly scrubbed with green soap and water The soap is then rinsed off with sterile saline, and the limb is cleansed with ether A suitable antiseptic is then applied, and the limb is wrapped in sterile drapes, fixed by bandages to prevent slippage (The bacterial flora of the skin may be materially reduced by using a soap containing 2 per cent G-11 compound for five minutes twice daily during the week prior to operation)

In **immediate amputation** following trauma or indicated by severe uncontrolled infection, this step must necessarily be omitted, but the limb is shaved and washed with soap and water, and general cleansing of the wound is carried out, i e , all gross dirt and necrotic tissue lying loose in the wound are removed and the wound is irrigated with saline solution

At the time of operation the patient is usually placed in the supine **position** Sandbags are put beneath the hip and shoulder, as required, and the pneumatic tourniquet is applied (The tourniquet is used in all amputation surgery if the segment above the level of amputation is long enough and if it is not contraindicated by the presence of peripheral vascular disease) Any sterile drapes are then removed, and the stump is cleansed again with ether, and, finally, painted with a suitable antiseptic If the procedure is the repair of an open amputation, care is taken not to contaminate the normal skin from the granulating area, and the granulations are seared with the actual cautery or with a silver

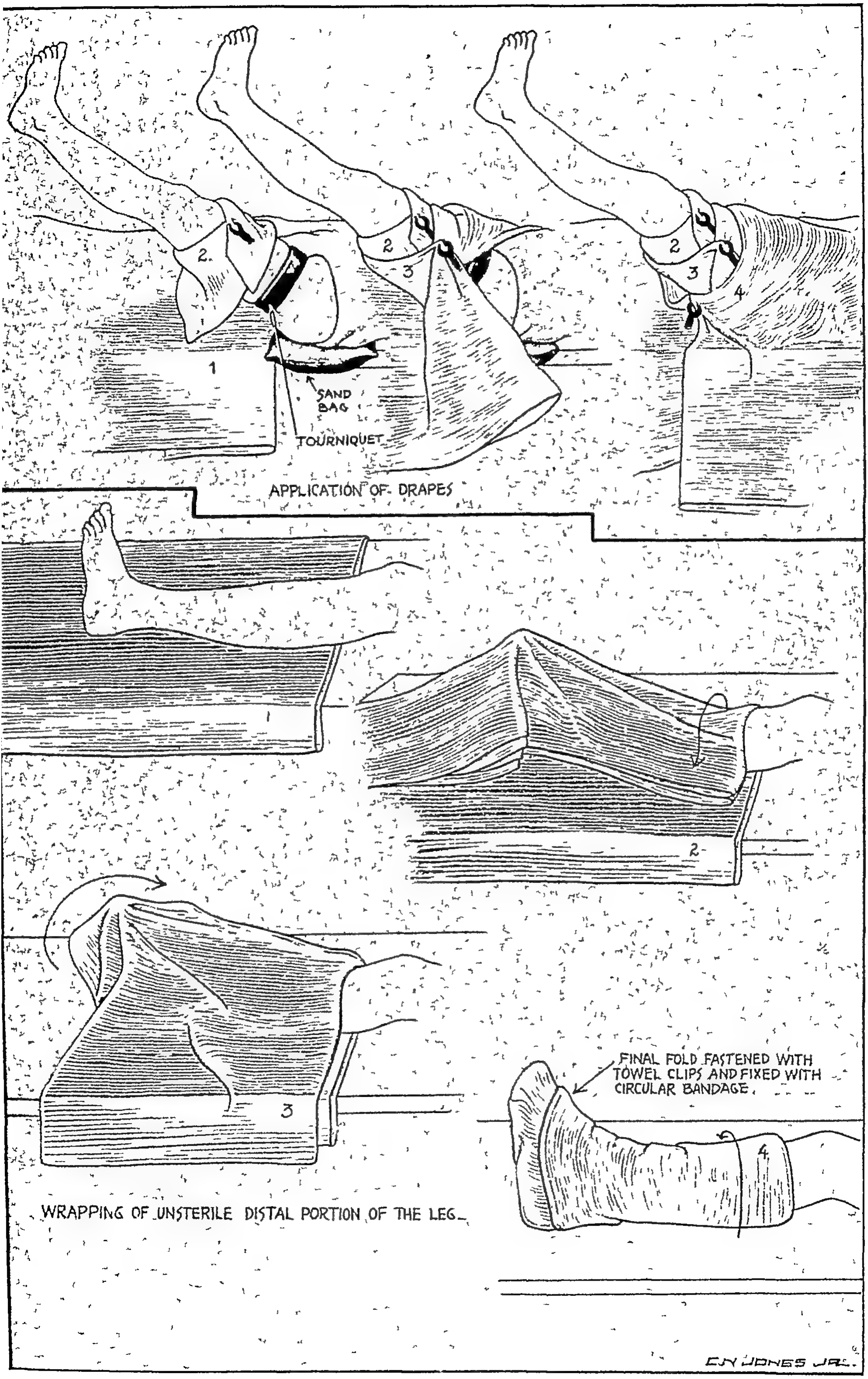

2.
2
3
2
3
4
1
SAND BAG
TOURNIQUET
APPLICATION OF DRAPES
1
2
3
WRAPPING OF UNSTERILE DISTAL PORTION OF THE LEG
FINAL FOLD FASTENED WITH TOWEL CLIPS AND FIXED WITH CIRCULAR BANDAGE.
4
C.H. JONES JR.

Fig 32

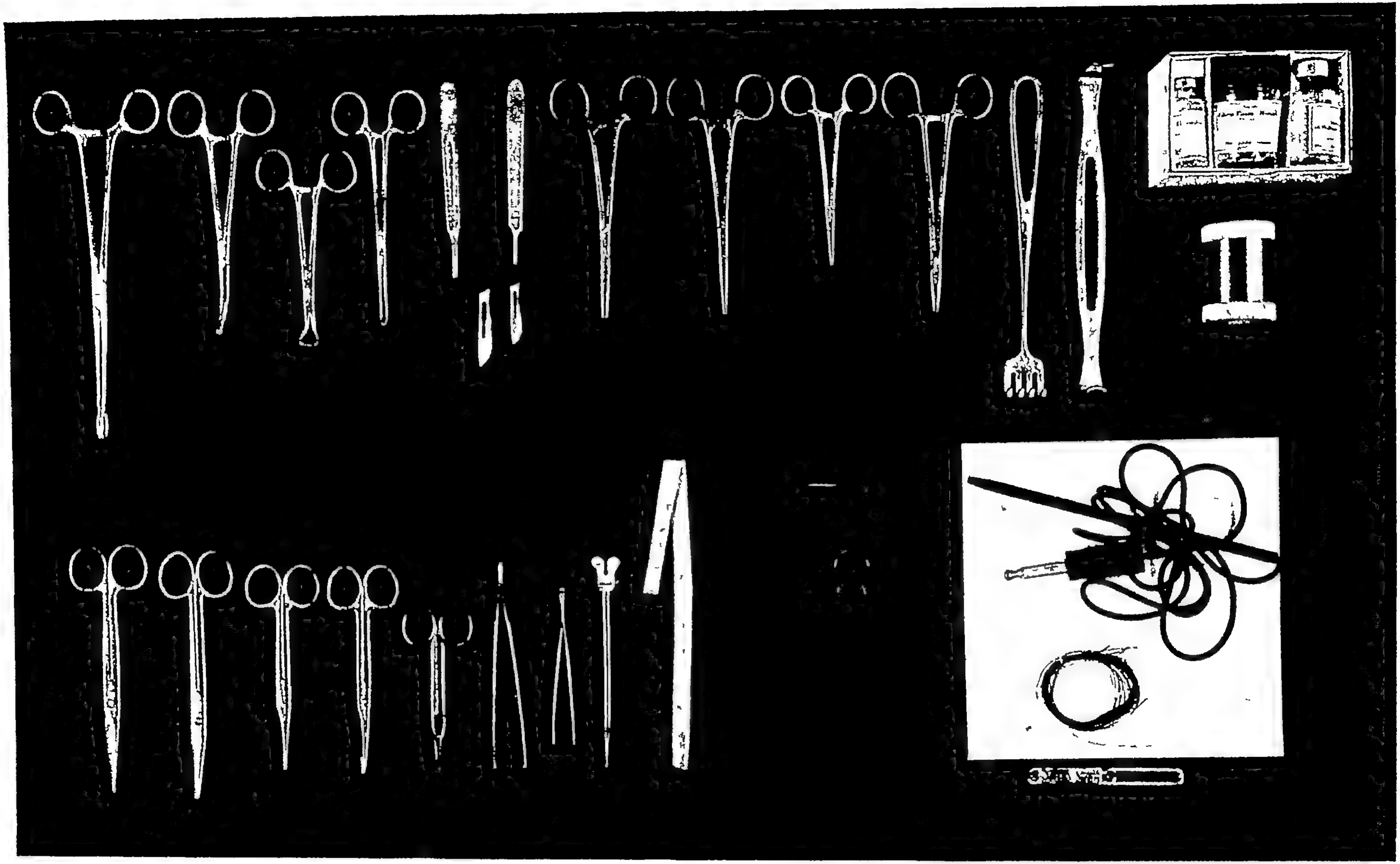


Fig 33.—General instrument set (Walter Reed General Hospital Neg No 4762 A2)

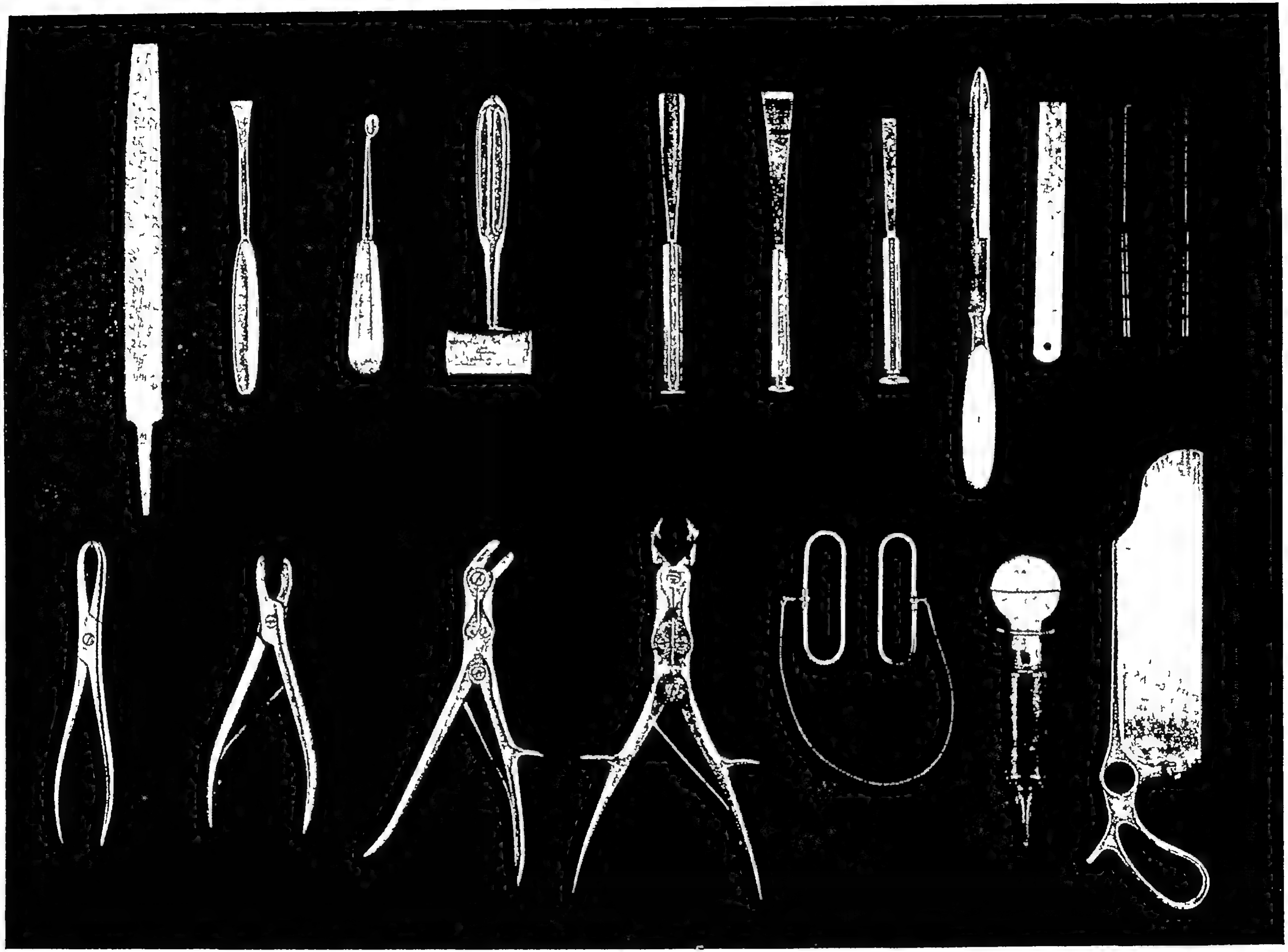


Fig. 34.—Special instruments used in amputation surgery. (Walter Reed General Hospital Neg. No. 4762 A3.)

nitrate stick to minimize the danger of contamination during the subsequent procedure The limb is then draped

The technique of **draping** the extremity may follow any of the accepted methods used in orthopaedic surgery I have found the following method satisfactory

(a) After the surgical preparation of the patient is complete, the limb is elevated and a sterile sheet placed beneath it and across the full width of the operating table, extending to a point several inches above the prepared area A sterile towel is now placed circumferentially about the most proximal portion of the prepared area and fixed with a towel clip A second sheet is placed beneath the limb on top of the first sheet Its upper end is passed about the limb at the lower edge of the towel and fixed with a towel clip A third sheet is placed over the body from above, in such a manner that its lower end circles the leg at the upper end of the prepared area The accompanying illustration shows the technique, with the circling drapes about the limb spread somewhat for clarity Further drapes are placed as necessary to complete the sterile field

(b) It is frequently necessary to drape off the unprepared or infected distal end of an extremity To accomplish this a small sterile sheet is placed on the operating table over the sterile drapes at a point high enough to insure that its upper end will fall within the prepared area The unsterile assistant places the limb in the mid-portion of the sheet The right-hand side of the sheet is folded over the unsterile portion of the limb to cover it completely, and the bottom of the sheet is folded upward Finally, the left-hand side of the sheet is folded over the top of the extremity so that it encircles the entire limb at that level The sheet is fixed in position by towel clips and then wrapped by a sterile elastic or muslin bandage This completely eliminates the contaminated area from the clean surgical field

INSTRUMENTS AND SURGICAL SUPPLIES

Soft Part Instruments	*General Set*	*Hip and Shoulder*	*Fingers, Hand, and Forefoot*
1 Forceps, hemostatic, Ochsner	6	12	3
2 Forceps, hemostatic, straight (Kelly)	18	36	6
curved (Kelly)	12	24	4
3 Forceps, hemostatic, mosquito	12	12	12
4 Forceps, tissue, Allis	6	12	6
5 Forceps, towel, 3″	6	6	6
5½″	4	6	4
6 Forceps, tissue, smooth, 5½″	2	2	2
7 Forceps, tissue, mouse tooth, small	0	0	1
large	2	2	2
8 Forceps, tissue, Adson Dural	0	0	1
9 Periosteal elevator, narrow	1	1	1
wide	1	1	1
10 Knife handle No 3	1	1	1
No 4	2	2	1
11 Knife blades	#21, #11	#21, #11	#11, #15, #21
12 Rake retractors, sharp medium	2	2	2
small	0	0	2
13 Army retractors or Hibbs, small	2	2	2
14 Richardson retractors or Hibbs, medium	0	2	0
15 Vein retractors	0	0	2
16 Probe, or groove director	1	1	1
17 Scissors, dissection, straight, large	1	1	1
small	1	1	1
18 Scissors, dissecting, curved large	1	1	1
small	1	1	1
19 Scissors, suture	1	1	1
20 Scissors wire (elective)	1	1	1

	General Set	Hip and Shoulder	Fingers, Hand, and Forefoot
Bone Instruments			
1 Periosteal elevators, sm 13	1	1	1
2 Bone holding forceps, medium	1	1	1
3 Bone cutting forceps, Hibbs, or straight	1	1	1
4 Double action rongeurs, large	1	1	0
small	0	0	1
5 Bone hook	1	1	0
6 Chisels, small	1	1	1
medium	1	1	1
large	1	1	0
7 Gouges, small	1	1	1
medium	1	1	1
large	1	1	0
8 Curettes, small	1	1	1
medium	1	1	1
large	1	1	1
9 Gigli saws	2	2	2
10 Amputation saw	1	1	1 (foot)
11 Metacarpal saw	0	0	1
12 Amputation knife	1	1	0
13 Rasp	1	1	1
14 Bone file	1	1	1
15 Mallet	1	1	1
16 Steel rule	1	1	1
17 Amputation block	1	1	0
Sutures			
For the deep tissues			
000 plain catgut	0	0	1
00 plain catgut	2	2	2
0 plain catgut	2	2	0
No 2 plain catgut	1	2	0
For the skin			
Cotton,			
Silk suture, or			
Stainless steel wire, No 34 & 36			
Miscellaneous			
1 Fibrin foam			
2 Asepto syringe	1	1	1
3 2 c c hypodermic syringe with needle, gauge 22, 1½" long (elective)	1	1	1
4 10 c c Novocain, 2% solution (elective)			
Tourniquets			
1 Desired type (pneumatic, Esmarch, Martin, or rubber tubing)	1	1	1
Supplies (sterile)			
1 Petrolatum gauze scarlet red gauze or aquaform penicillin gauze			
2 Sheet wadding			
3 Ace bandage			
4 Stockinette			
5 Penrose drain			
Supplies (unsterile)			
1 Ace adherent			
2 Plaster of-Paris			
3 4 inch biased muslin bandage			
4 Yuca board splints			
5 Rope and pulleys			
Prep Tray			
1 Forceps, sponge	8	8	8
2 Soap solution	250 c c	250 c c	250 c c
3 Saline	250 c c	250 c c	250 c c
4 Ether	60 c c	60 c c	60 c c
5 Antiseptic	100 c c	100 c c	100 c c

IV. ANESTHESIA

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INTRODUCTION

There is a wide variety of anesthetic drugs available for rendering limbs insensitive to operative manipulation, and there are also many techniques for administering these agents. Because of the important part which proper anesthesia plays in determining the success of surgical procedures and the welfare of the patient, a review of the more pertinent factors concerned in the selection of these anesthetic agents and techniques is indicated here.

Almost the only demands which the surgeon places upon anesthesia are the delivery of pain relief for the dissection, and the obtundation of ischemic pain during the application of the tourniquet, profound muscular relaxation is rarely necessary. Thus, from the surgical point of view, anesthesia will be adequate if the patient feels no pain and exhibits no movements of the extremity during operation.

From the viewpoint of the anesthesiologist, however, there is another factor which must be considered—that is, the effect which the anesthetic drug and technique to be chosen will have upon the general body processes of the individual. This becomes increasingly significant in the face of the physiological disturbances which are usually present following disease or injury.

Thus it is apparent that the selection of anesthesia must be made on an individual basis and in the light of the circumstances attendant, and that it would be both impossible and ill-advised to recommend a specific anesthetic agent or technique for a specific type of amputation. Therefore, in the following pages, emphasis will be placed upon physiological principles and upon the modifications imposed upon the organism by the action of anesthetic drugs.

To describe completely and evaluate critically the numerous anesthetic methods which can be used is beyond the scope of this writing. The important factors will be developed and summarized. A short, illustrated description is included to facilitate the performance of the common nerve blocks most useful in surgery of the extremities. Finally, consideration is given to some of the aspects of the painful states consequent to amputation.

PREANESTHETIC MEDICATION

The period of anesthesia begins with the administration of various hypnotics and sedatives preoperatively. These drugs are employed for the protection and comfort of the patient.

Psychic sedation although important for *all surgical manipulations*, is of particular value in lessening the rather distressing implications occasioned by the prospective loss of a limb. Ordinarily, time is not available for proper psychotherapy for the amputee until convalescence is established. The proper selection of premedicant drugs aids considerably in tiding the patient over this difficult period. Further force *is imparted to this consideration if a form of* anesthesia permitting retention of the conscious state is selected. In addition

premedicant drugs are of great value in inhibiting various undesirable side effects of anesthetic agents and, also, in decreasing the dosage of those agents required for the completion of the surgical task

The anesthetic agents to be selected and the physical status of the patient determine the types of preanesthetic drugs as well as their amounts The short-acting barbiturates, given orally about two hours before operation, are important constituents of the preanesthetic regime if local, regional, or spinal anesthesia is to be employed, since they minimize the dangers of toxic reactions to the anesthetic drugs and effect hypnosis It must be remembered, however, that no analgesia is afforded by the barbiturates, and, unless an appropriate opiate or other analgesic is added, the perception of pre-existing pain may be accentuated Ordinarily, the barbiturates are not necessary adjuncts to inhalation or intravenous anesthesia

The opiates are commonly used for premedication Although Pantopon and Dilaudid have been utilized to advantage, morphine is the most common and possibly the most efficient It reduces the general level of metabolism, induces analgesia, and aids in the dissipation of fear It has no value and may be injurious in the presence of severe diabetes, shock, and for the aged If an anesthetic drug of low potency such as nitrous oxide or ethylene is selected, proportionately larger doses of morphine should be administered to permit the maintenance of surgical anesthesia without hypoxia Contrariwise, large doses of morphine prior to the administration of cyclopropane may result in apnea in even the lighter planes of anesthesia Etherized patients will tolerate more morphine than those anesthetized with cyclopropane without untoward effects Morphine is necessary in the preparation of patients for local, regional, or spinal analgesia

Morphine is best combined with scopolamine or atropine in the ratio of 25 to 1 When given subcutaneously, sixty to ninety minutes must be allowed for the desired effect

The belladonna drugs are useful prophylactically in the reduction of excessive respiratory tract secretions and have a decided protective influence against some undesirable reflex responses during anesthesia Atropine is most useful in the very young, the aged, and is of particular value as a predecessor to Pentothal anesthesia Scopolamine is the drug of choice for most adults and affords a pleasant type of psychic soothing in addition to functioning as counterpoint to the respiratory depression of morphine Atropine and scopolamine are frequently unnecessary as precursors to regional or local anesthesia, unless supplementation with a general narcotic is elected One of these drugs is essential in preparation for inhalation or intravenous anesthesia unless a definite tachycardia is present

INHALATION ANESTHESIA

When inhalation anesthesia is selected for the obtundation of pain during amputation, stress must be placed upon meticulous attention to skillful technique in all instances, but particularly when factors intrinsic in the condition of the patient are of concern Anesthesia for the diabetic, the cardiac, the aged, the malnourished, and the patient in shock requires careful insurance of adequate oxygenation, a patent airway, and efficient absorption of exhaled carbon dioxide at all times, regardless of the specific agent selected

One of the more difficult problems which arises in the use of inhalation methods for emergency cases is emesis The administration of morphine, frequently in large doses, the full stomach, the cessation of gastrointestinal peristalsis, and inadequate time for proper preparation contribute to the incidence

of vomiting. The consequences may be serious if aspiration of vomitus occurs, and a faulty induction of anesthesia will almost guarantee emesis. Avoidance of this accident is not always possible, even with efficient anesthetic management, and, therefore, observance of certain precautions is of importance. If vomiting occurs during induction, before the protective reflexes have disappeared, complete gastric emptying should be permitted by removal of the anesthetic appliances and with the patient placed in the lateral posture in Trendelenburg position on the operating table, before anesthesia is resumed. After anesthesia is again secured, a depth of second plane of surgical anesthesia must be maintained to insure against stimulation of the vomiting reflex. Vomiting is to be expected again during recovery, and identical precautions are indicated. In instances where aspiration of vomitus is suspected, bronchoscopic suction by the anesthetist must be performed to avoid the sequelae of atelectasis or severe pulmonary infection.

The least toxic of the inhalant anesthetic agents is nitrous oxide. It is also the most difficult to administer in concentrations which avoid hypoxia. This gas has its greatest usefulness in the management of elderly patients and will rarely be relied upon as the sole agent for amputation in patients other than the aged. Whenever chosen, oxygen should be at least 20 per cent of the mixture.

The indications for ethylene anesthesia are similar to those for nitrous oxide, although greater potency is available.

Ether has been chosen for a great many amputations. It has a large margin of safety, and, in inexpert hands, is likely to have fewer noxious consequences than other inhalation agents. Ether, whether preceded by nitrous oxide or alone, has definite limitations in facilitating emergency amputation associated with trauma or hemorrhage. Emesis and aspiration of vomitus are more likely to occur during ether anesthesia in emergency circumstances than during the administration of other volatile liquids or the gases. Furthermore, if shock and more particularly hemorrhage are evident, ether will aggravate an already depressed peripheral circulation. When amputation is indicated in patients with diabetes or renal impairment, etherization provides an additional burden by further deranging carbohydrate metabolism and kidney function. However, ether still is a most useful drug and, except in the instances outlined, may be employed with considerable satisfaction.

Considerable controversy has centered about cyclopropane in recent years, particularly because of its effect upon cardiac irritability. If used in patients with disturbances of the cardiac conduction mechanisms, it must be very cautiously administered. If arrhythmia develops during anesthesia in a previously normal heart, a change of agent is indicated. Since ether abolishes the abnormalities of rhythm induced by cyclopropane, its use in these circumstances is indicated. Cyclopropane is most valuable when rapid, nonirritating induction is desired, as in emergency amputation. Its efficacy in producing a beneficial effect in hemorrhage and possibly shock makes it the drug of choice in amputation necessitated by trauma. There is no evidence that kidney or liver function is impaired by cyclopropane, an important consideration in the aged, malnourished, or the victims of hepatic or renal disease. The diabetic patient is more safely anesthetized with cyclopropane than with ether, although there is evidence that the former is not without ill effects upon the intermediary carbohydrate metabolism.

Little need be added about chloroform. Vinethene, ethyl chloride, or trichlorethylene. These drugs are either dangerous or lacking in qualities suitable for amputation. They deserve little consideration in the anesthetic management of amputations.

INTRAVENOUS ANESTHESIA

Intravenous anesthesia for all practical purposes is synonymous with Pentothal Sodium anesthesia, although anesthesia can be effected by vein with other drugs. As sole agent in the usual concentrations of clinical use (2, 2.5, or 5 per cent), Pentothal is not effective in providing satisfactory anesthesia for amputation unless inordinately large doses are administered. Adequate pain relief is present, but frequent movements of the extremity are not uncommon when muscles, nerves, and bone are incised. This difficulty is obviated in part by supplementation with nitrous oxide and oxygen in nonhypoxic concentrations. The latter technique is better suited to the surgical needs of revisions of amputation and the dismemberment of small parts like digits than to the requirements of more extensive surgical manipulations upon the extremities.

In emergency amputation, Pentothal is useful as an induction aid in the prevention of emesis, but its administration must be exceedingly cautious because of the deleterious effect upon shock and hemorrhage.

The most efficacious employment of Pentothal for amputation is in conjunction with local, regional, and spinal anesthesia to effect an unconscious state when such is desirable for psychic reasons. It is also of significant value for the insurance of pleasant inductions. Finally, carbohydrate metabolism is not significantly altered, a factor of importance in the conduct of anesthesia for the patient with diabetes.

REFRIGERATION ANESTHESIA

Refrigeration of tissues as a method of producing analgesia for amputation has excited interest and enthusiasm in recent years. The technique is most suitable for aged patients and in instances where overwhelming infection makes amputation mandatory as a lifesaving measure. The completion of refrigeration anesthesia is tedious and time consuming. Although adequate analgesia is provided, its ultimate place in the management of amputations will rest upon the surgical results rather than upon its role in anesthesia, since the problem of pain relief alone is readily and safely accomplished, even for the very poor-risk patient, with any one of several other methods.

SPINAL ANESTHESIA

Spinal anesthesia actually is a widespread form of regional anesthesia performed in a special manner. Since, in large part, the limiting factors of safety are concerned with the extent of anesthesia produced by intrathecal injection of a local anesthetic drug, properly executed spinal anesthesia may be employed to advantage for lower extremity amputations. Analgesia of the lumbar and sacral segments is usually adequate for amputations, although occasionally blockade to the tenth thoracic segment is indicated to obtund tourniquet pain or for operative procedures involving radical dissection in the suprapubic area. In any event, the serious complications of spinal anesthesia—hypotension and respiratory depression—are rare and minimal in levels required for the surgical manipulations discussed.

Although technical achievement of low spinal anesthesia is not difficult, certain fundamentals are useful guides. Slow injection of hyperbaric solutions with the patient in slight Fowler position will usually insure the desired level. Solutions may be weighted with procaine (if Pontocaine is the chief agent), or with glucose or plasma, regardless of the drug employed. Small volumes, consistent with the upper limits of safety as to concentration of anesthetic drugs, are of help in preventing diffusion cephalad. The site of injection is considered of importance by some anesthetists. For this class of operations, a low inter-

space is suggested. Recently, a directional needle has been designed to facilitate the diffusion of drugs caudad or cephalad. This technique may prove of considerable value in the localization of analgesia to the desired dermatomes.

Procaine is the best known and least toxic of the drugs administered intrathecally. However Monocaine, Metycaine, and Intracaine are equally satisfactory in proper dose and dilution. Pontocaine is usefully employed for procedures requiring more than one hour and less than two and one-half hours. For amputations extending beyond this time, continuous spinal technique with procaine is desirable.

Spinal anesthesia is undesirable in patients suffering from shock, hemorrhage, or hypertension. The anxious, excited, or neurotic subject is a poor candidate for this technique. It is of value for the diabetic patient, the patient with peripheral vascular disease, and in subjects not in the categories of contraindication previously mentioned.

INFILTRATION ANESTHESIA

Infiltration anesthesia with procaine or any other local anesthetic agent has only limited application in facilitating amputations. It is time consuming and frequently necessitates reinforcement with intravenous anesthesia or nerve blocking. The method is not to be used in or near tissues with impaired viability resulting from ischemia or infection. It is also a poor choice for analgesia in emotionally unstable patients or those in considerable pain. Its utility in revisions or in the line of incision for flaps is debatable because of the possibility of retarding healing in an area to be subjected to weight-bearing.

NERVE BLOCK

Analgesia obtained by the deposition of solutions of local anesthetic drugs near nerve trunks is frequently desirable in amputation surgery. It has a definite place in the management of upper and lower extremity amputations, but probably is utilized to better advantage in the former, largely because efficient regional anesthesia of the latter may be secured more simply with spinal block.

Although Metycaine, Intracaine, or Monocaine are successfully employed, procaine is the usual choice because of its familiarity and relatively low toxicity. Rarely is a concentration greater than 2 per cent indicated. A total dose of 1 Gm. may ordinarily be considered maximum. When epinephrine is employed, 0.5 cc. (1:1000) is added to 50 cc. of anesthetic solution. Epinephrine is contraindicated in patients with hypertension and hyperthyroidism.

Nerve block anesthesia is suitable in operative procedures extending up to two hours in time. It is a poor choice for unstable and emotional subjects, or in instances where the sites of injection exhibit infection or impaired viability.

The illustrations and discussion of the various nerve blocks employed in facilitating amputation are self-explanatory. Only one method for each block is presented, usually the procedure simplest to perform and consistent with a high percentage of success. The sympathetic blocks are included because of their employment preoperatively to improve circulation and thus permit lower levels of amputation, and because of their role in the management of painful sequelae following operation.

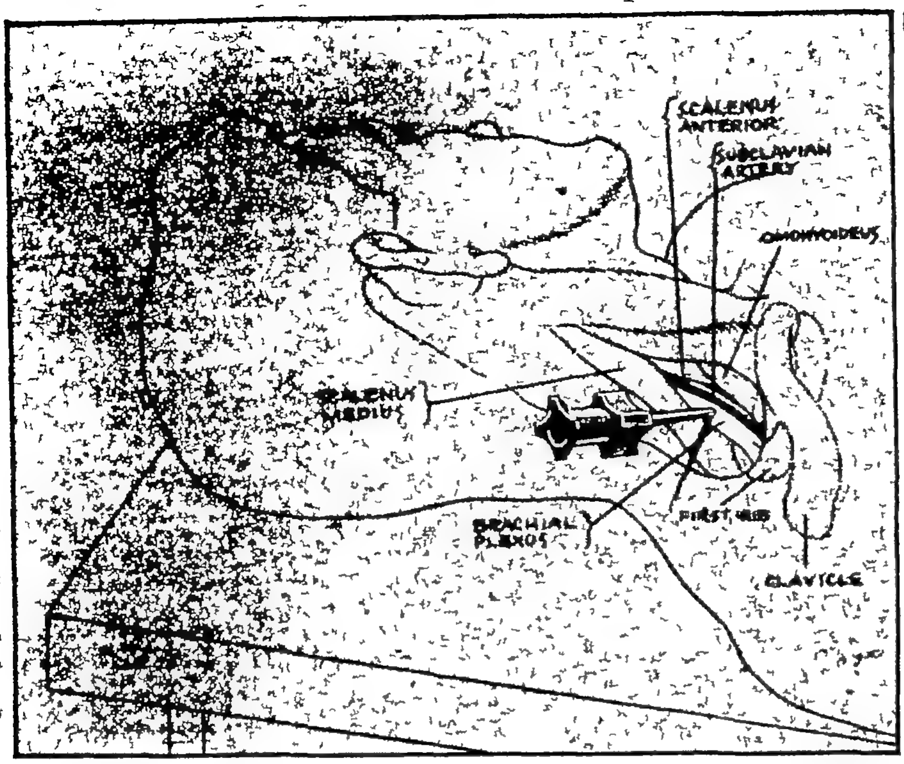
1. Brachial Plexus Block

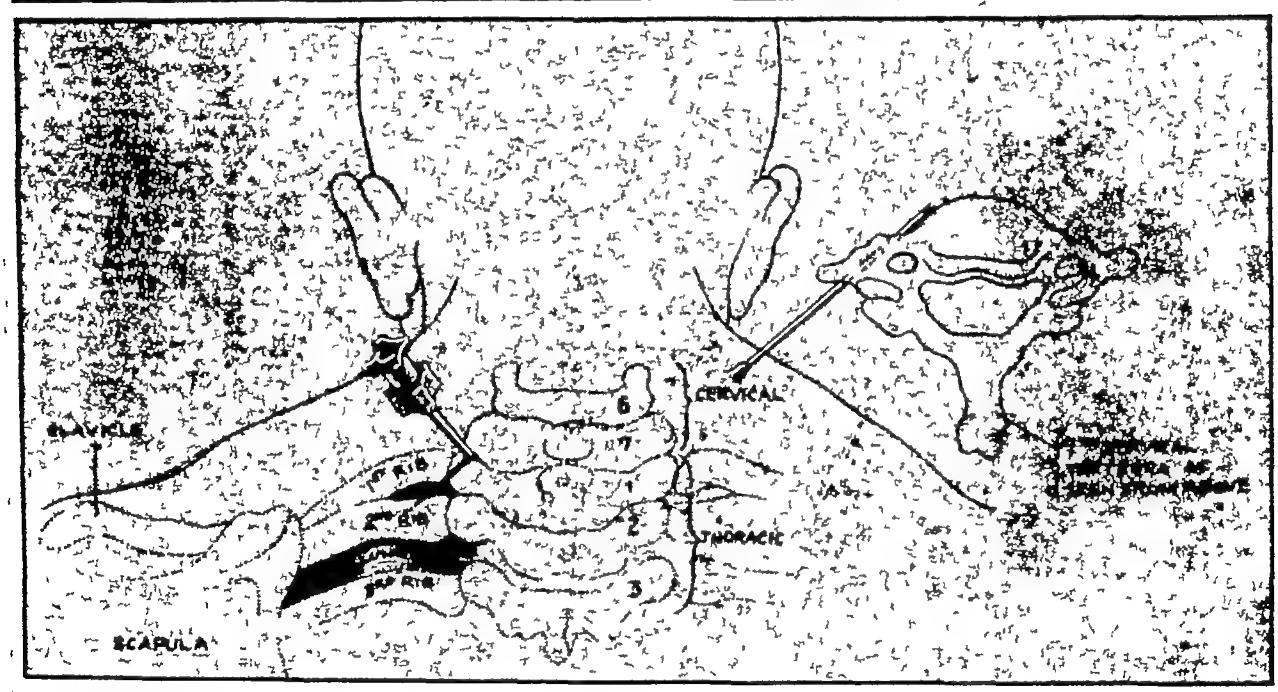
a. **Indication.** Amputations upon the upper extremity below the proximal third of the arm may be performed with brachial plexus block.

b. **Solution.** 25 to 40 cc. of 2 per cent procaine.

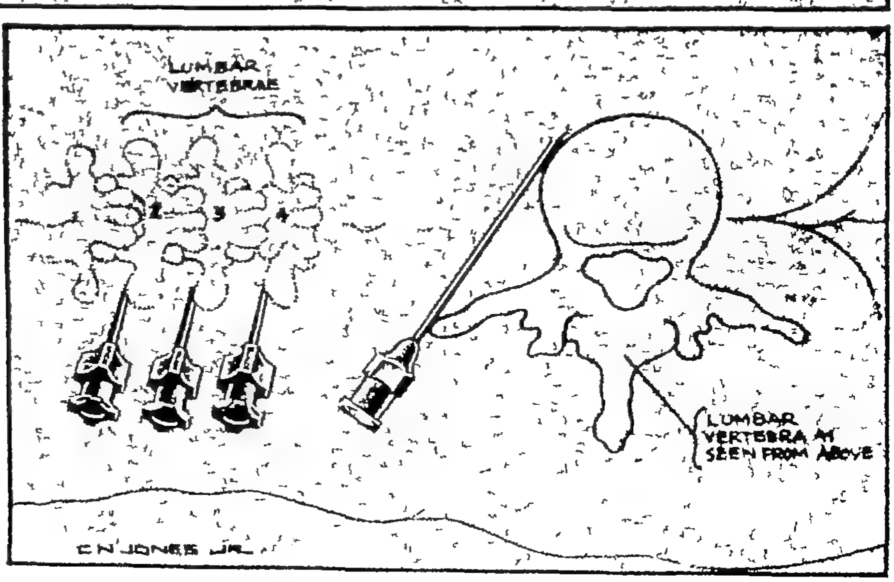
c. **Technique.** The patient is placed in the supine position with no elevation of shoulders or head. The head is then turned toward the opposite side

1. BRACHIAL PLEXUS BLOCK





2 STELLATE GANGLION BLOCK (POSTERIOR)



3 LUMBAR SYMPATHETIC BLOCK (POSTERIOR)

Fig 35

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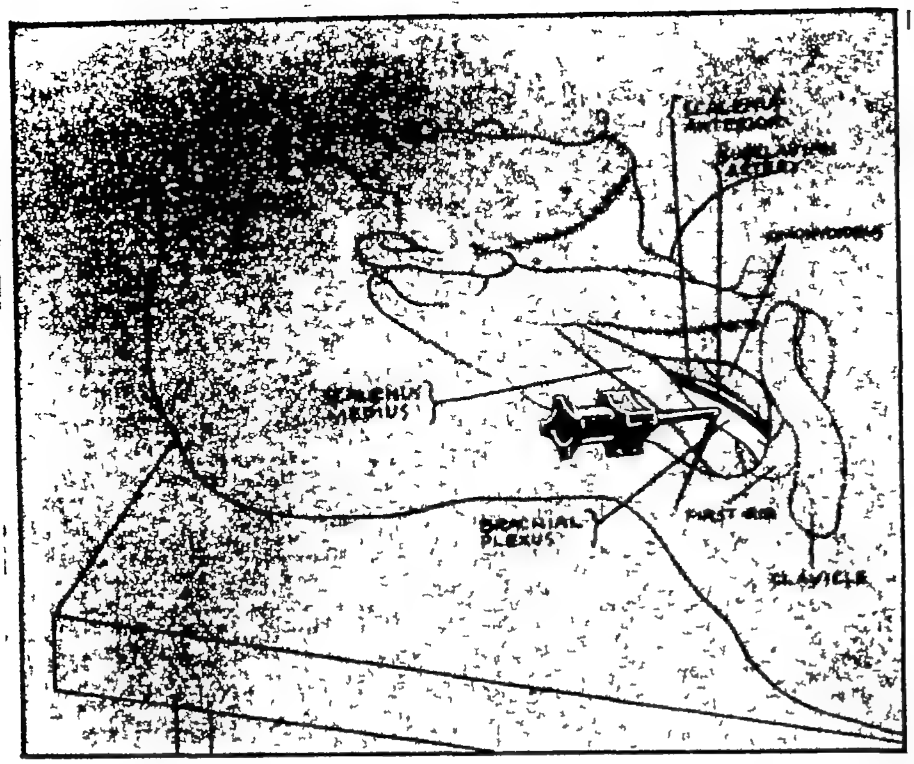
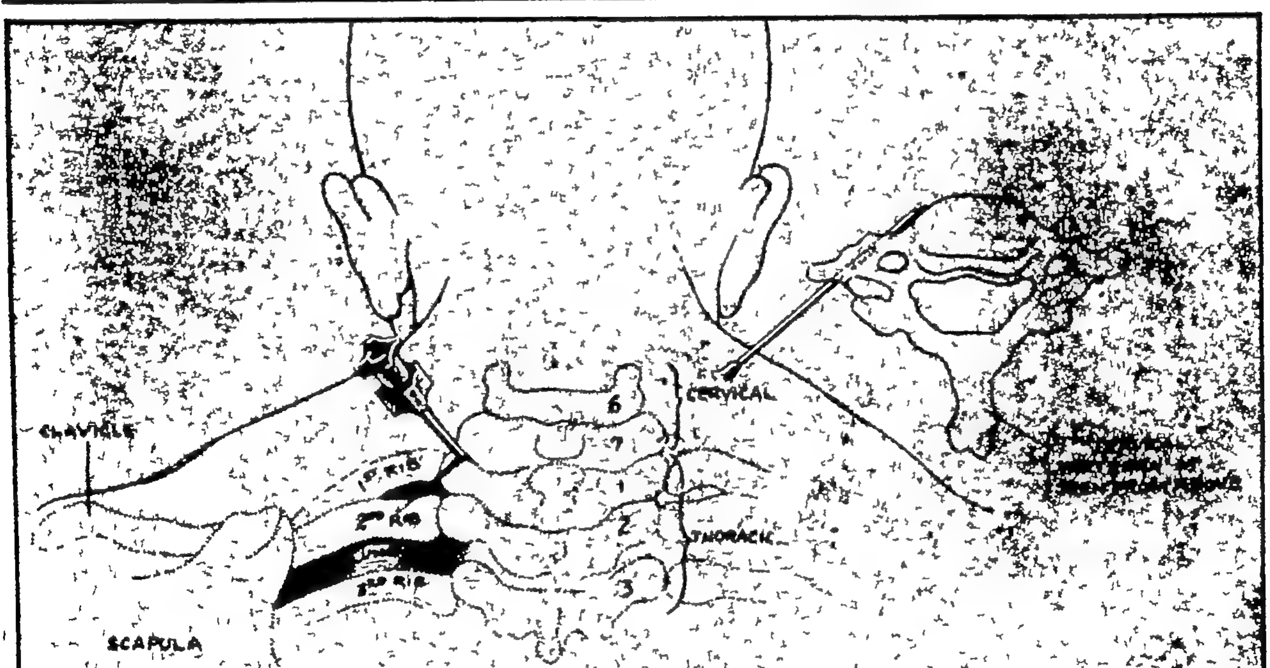
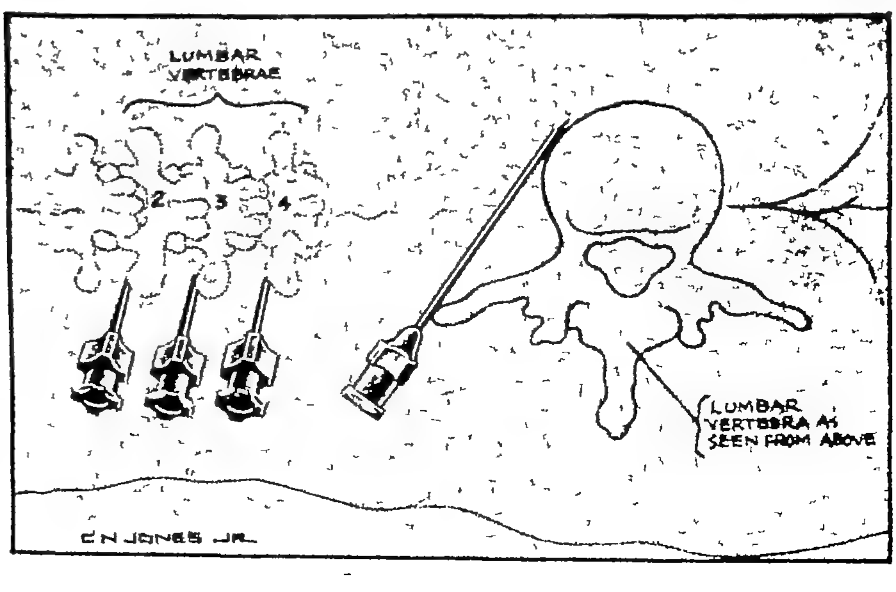




2 STELLATE GANGLION BLOCK (POSTERIOR)



3 LUMBAR SYMPATHETIC BLOCK (POSTERIOR)

Fig 35

so that the chin is near the contralateral shoulder A skin wheal is raised 2 cm above the clavicle, just over the lateral edge of the anterior scalene muscle A 5 cm needle of fine calibre, mounted on a syringe, is inserted through the wheal caudad, at an angle of 45 degrees with the skin of the neck toward the brachial plexus and first rib Paresthesia in the forearm or hand should be obtained Adequate anesthesia is assured if the solution is injected at the site of paresthesia If paresthesia is not obtained before the needle impinges upon the first rib, redirection at a slightly different angle is indicated Adequate anesthesia develops in ten to fifteen minutes It is unnecessary to infiltrate near each of the various cords or trunks individually

d Complications

Pneumothorax is possible, since the dome of the pleura extends above the first rib and is close to the path of the needle The symptoms appear almost immediately and consist of chest pain and dyspnea The utilization of an attached needle and syringe minimizes the danger of allowing air into a punctured pleura Pneumothorax occurred twice in 510 brachial blocks performed in one series

Intravascular injection may occur because of the proximity of the subclavian artery and various neck veins to the brachial plexus Careful aspiration will prevent this complication

2 Stellate Ganglion Block

a **Indications** Block of the stellate ganglion is indicated in acute injury to the upper extremity complicated by vascular spasm Successful interruption of vasoconstrictor impulses may, on occasion, provide adequate blood flow to an extremity and obviate the necessity for amputation of an ischemic limb More frequently, by promoting proper function of the collateral vessels, lower level amputation than appeared necessary upon first examination may become possible Stellate ganglion block is also an important component in the management of patients with phantom limb pain

b **Solution.** 10 to 15 c c of 1 per cent procaine

c **Technique** The patient is placed in the sitting position The neck is moderately flexed to accentuate the curvature of the upper thoracic and lower cervical spines The interspace between the seventh cervical and first thoracic spinous processes is palpated, and a skin wheal is raised 4 cm lateral to this point A fine-calibre 8 cm needle is inserted perpendicularly until contact is made with the transverse process of the first thoracic vertebra The needle is then redirected, medially and above the transverse process, toward the body of the vertebra Insertion in this direction is continued until the needle point is opposite the anterior surface of the vertebra Injection is completed at this point Successful block will result in an ipsilateral Horner's syndrome, anhidrosis, and increased skin temperature of the extremity

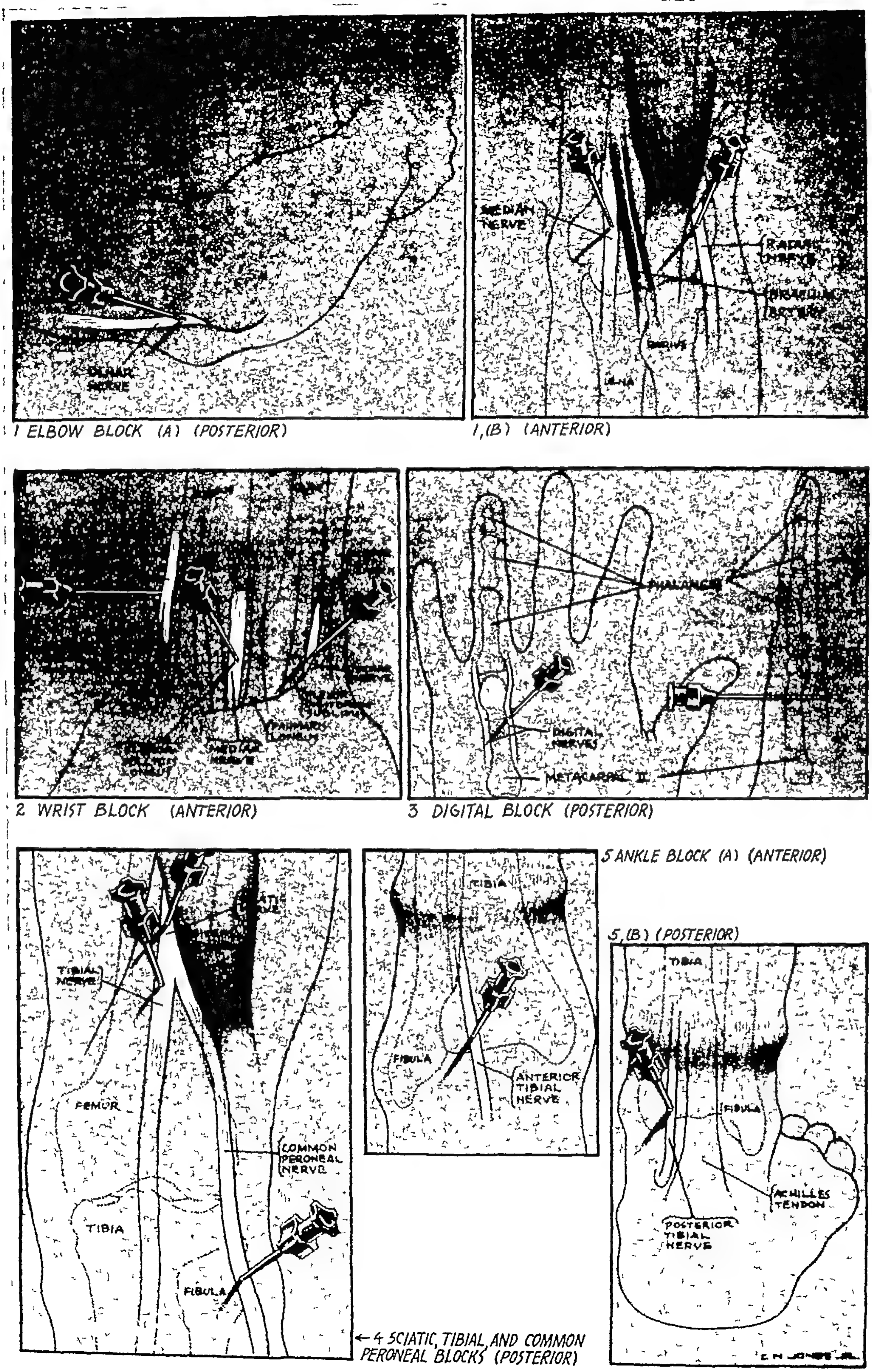
d **Complications**

Pneumothorax is the most frequent accident but may be avoided by exercising great care in technique and utilizing a needle closed by a stilette

Subarachnoid injection is not common but may be grave in its consequences because of the attendant significant circulatory depression and respiratory failure Careful check by aspiration for spinal fluid is most important

3 Lumbar Sympathetic Block

a **Indications** Lumbar sympathetic interruption is indicated for the lower extremity in the same circumstances outlined for the utilization of stellate ganglion block in the upper



ULNAR NERVE
1 ELBOW BLOCK (A) (POSTERIOR)
MEDIAN NERVE
RADIAL NERVE
BRACHIAL ARTERY
ULNA
1,(B) (ANTERIOR)
MEDIAN NERVE
2 WRIST BLOCK (ANTERIOR)
PHALANGES
DIGITAL NERVES
METACARPAL II
3 DIGITAL BLOCK (POSTERIOR)
TIBIAL NERVE
FEMUR
COMMON PERONEAL NERVE
TIBIA
FIBULA
4 SCIATIC, TIBIAL, AND COMMON PERONEAL BLOCKS (POSTERIOR)
5 ANKLE BLOCK (A) (ANTERIOR)
TIBIA
FIBULA
ANTERIOR TIBIAL NERVE
5,(B) (POSTERIOR)
TIBIA
FIBULA
ACHILLES TENDON
POSTERIOR TIBIAL NERVE

Fig 36

b **Solution** 10 c c of 1 per cent procaine near each ganglion

c **Technique** The patient is placed in the prone position with the hips elevated The spinous processes of the second, third, and fourth lumbar vertebrae are identified Skin wheals are raised 5 cm lateral to the lower border of each of these processes Ten centimeter needles of fine calibre are passed through the skin wheals with the point angled slightly medially The needles are inserted until contact is made with the vertebral bodies They are then advanced until contact with the anterolateral surfaces of the bodies is barely lost Injection is then carried out Proper block results in skin drying and increased skin temperature in the lower extremity

d **Complications** Subarachnoid block and intravascular injection are the major harmful sequelae Careful aspiration will avoid both

4 Elbow Block

a **Indications** Nerve block at the elbow may be employed for amputations through the forearm, wrist, or hand and should be reinforced by a subcutaneous ring above the elbow

b **Solution** 3 to 10 c c of 2 per cent procaine for each nerve

c **Technique**

Ulnar Nerve The patient is placed in the supine position and the elbow partly flexed in a crude arc above the patient s chest The groove formed by the olecranon process of the ulna and the medial condyle of the humerus is identified A wheal is raised immediately above the groove A 5 cm needle connected with a syringe is inserted tangentially to the forearm, almost parallel with the nerve When paresthesia is obtained, the anesthetic solution is deposited In the absence of paresthesia, infiltration from skin to bone is completed Anesthesia is evident in five to ten minutes

Median Nerve With the elbow in extension and the forearm in supination, a transverse line is drawn across the anterior surface of the lower arm, approximately 1 cm above the condyles of the humerus The brachial artery and the biceps tendon are identified by palpation A skin wheal is raised on the transverse line adjacent to the medial aspect of the brachial artery, a point usually midway between the inner aspect of the biceps tendon and the medial condyle of the humerus A 5 cm needle connected with a syringe is inserted perpendicularly to the skin and advanced posteriorly past the deep fascia until paresthesia is obtained, when injection is completed If paresthesia is not obtained, infiltration beneath the deep fascia in the vicinity of the nerve is performed Anesthesia occurs in five to ten minutes

Radial Nerve The upper extremity is maintained in the position described for block of the median nerve A skin wheal is raised just lateral to the biceps tendon and on the transverse line drawn previously A 5 cm needle is inserted perpendicularly to the skin and advanced toward the posterior aspect of the lateral condyle of the humerus until paresthesia is obtained Injection is made when the nerve is touched by the needle However, if paresthesia is not obtained, infiltration is effected adjacent to bone and immediately anterior to it in the soft tissues Anesthesia appears in approximately ten minutes

d **Complications** None

5 Wrist Block

a **Indications** Wrist block is indicated for amputations in the hand or upon the fingers

b **Solution** 3 to 5 c c of 2 per cent procaine for each nerve

c **Technique** The forearm is extended and maintained in supination A line is drawn transversely across the anterior aspect of the wrist at the level of the styloid process of the ulna The ulnar nerve is blocked at a point lateral to the flexor carpi ulnaris and medial to the ulnar artery on the transverse line Injection is completed when paresthesia is obtained or in its absence by infiltrating behind the tendon of the flexor carpi ulnaris

Block of the median nerve is effected through a wheal between the palmaris longus and the flexor carpi radialis on the transverse line If no paresthesia occurs, injection is made between the tendons subfascially and posterior to the flexor carpi radialis

The radial nerve is blocked 2 cm above the styloid process of the radius adjacent to the lateral surface of this bone where it is superficial

d **Complications** None

6 Digital Block

a **Indication.** Anesthesia of the digital nerves is used for amputation of a digit or disarticulation through the metacarpophalangeal joint

b **Solution** 8 c c of 1 per cent procaine (without epinephrine)

c **Technique** Two skin wheals are raised 1 cm proximal to the metacarpophalangeal joint along the sides of the metacarpal bone The wheals are connected by intracutaneous and subcutaneous injection Infiltration is then effected against both sides of the metacarpal bone with 3 c c near each digital nerve The block is completed by injection from dorsum to palm along either side of the bone

d **Complications.** None

7. Sciatic, Tibial, and Common Peroneal Block

a **Indication** Block of the sciatic or tibial and common peroneal nerves is employed for amputations of the leg and foot, but must be reinforced with a "garter" below the knee

b **Solution** 10 c c of 2 per cent procaine

c **Technique**

Sciatic and Tibial Nerves With the patient in the prone position and the knee extended, a triangle is constructed by outlining the bend of the knee and the internal edges of the semimembranosus and biceps femoris muscles The angle between the muscles is bisected and a wheal is raised on this line 7 to 9 cm above the bend of the knee joint An 8 cm needle is inserted perpendicularly until the deep fascia is penetrated Paresthesia will be induced by advancing the needle slightly further, and injection is completed Anesthesia of the entire sciatic nerve or only the tibial branch may be produced, depending on the level at which bifurcation of the former occurs

Common Peroneal Nerve A wheal is raised in the depression just below the head of the fibula on its posterolateral aspect A 5 cm needle is inserted and injection is made from skin to bone unless paresthesia is obtained, in which event injection is performed at the site of paresthesia

d **Complications** Rarely, foot drop may be produced by damage to the nerve during intraneural injection

8 Ankle Block

a **Indication** Accompanied by a subcutaneous and intracutaneous ring, injection of the anterior and posterior tibial nerves permits amputation in the foot

b **Solution** 10 c c of 1 per cent procaine for each nerve

c **Technique** *Anterior Tibial Nerve* A line is drawn across the anterior surface of the ankle between the prominences of both malleoli Midway between these points, a 5 cm needle is inserted toward the tibia Injection is completed if paresthesia is obtained, or is continued against the tibia if none occurs

Posterior Tibial Nerve The needle is inserted at a point adjacent to the medial side of the Achilles tendon on the same level as employed for the anterior tibial nerve Injection is performed upon the production of paresthesia or beneath the deep fascia overlying the posterior aspect of the tibia

d **Complications** None

PAINFUL SEQUELAE OF AMPUTATIONS

Once amputation is completed, rehabilitation of the patient, the fitting of a prosthesis, and instruction in its function remain important considerations for the orthopaedic surgeon However, this phase of management may be seriously impeded or altogether prevented if a painful stump ensues or phantom limb pain develops

There is no reliable method of prognosticating which amputee will be disabled by pain Regardless of the method of surgical closure or treatment of cut nerves, certain patients will exhibit stumps that are painful and tender Frequently, neuromata have been implicated as etiological factors Newly formed bursae underlying a prosthetic fixation or weight-bearing point may also result in discomfort after ambulation upon an artificial limb The treatment for these patients is difficult Attempts to infiltrate sensitive or "trigger" points with 1 per cent procaine are indicated A definite proportion of patients will be assisted considerably in the form of vast improvement in comfort or even cure of pain In others, resection of neuromata or scar revisions may be necessary Injection is simple, often valuable, and should be attempted before further operative interference is carried out Occasionally appropriate nerve block with procaine is the procedure of choice for therapeusis of painful stumps

Perhaps the most interesting, although baffling, postoperative complication in amputees is the presence of a phantom limb Although there is disagreement on the subject, competent observers have noted that the illusion of the presence of part of an amputated limb, usually the distal portion, is quite common Study of young amputees who were patients in a military hospital lends strong support to this thesis It seems dubious that this is a psychic phenomenon because of its widespread incidence in emotionally stable individuals

The presence of a phantom limb is inconsequential unless pain in the absent member supervenes Phantom limb pain varies in intensity and manifestations, but not infrequently its presence dominates the entire clinical problem and sharply arrests the necessary fitting of prostheses and education in their uses

The most disabling aspect of pain is the complaint that the ghost limb, usually the hand or foot, is held in a cramped position which cannot be released by the patient The accompanying pain may be of any variety, but usually the victim is affected by diffuse burning sensations which become unbearable The painful state is associated with hypermobility of stump musculature even to the extent of uncontrollable clonic jerkings The stump is also frequently cold and moist

The etiology of phantom limb pain is not established There are those who believe it is psychic in origin However, the results obtained by Livingston and others distinctly favor an organic interpretation implicated with dysfunction of neurophysiological mechanisms The explanation advanced is one of peripheral

irritation in the stump, causing the production of excessive response in the internuncial pool of the spinal cord which brings about the changes seen in the remaining portion of the extremity and the central projection and perception of the absent limb.

Treatment is difficult and all forms of therapy yield variable results. Ordinarily, stump revisions and removal of neuromata are associated with disappointing results. Infiltration of the appropriate sympathetic nerves offers promise in the management of phantom limb pain. Repeated injections will result in cure in many patients, although sympathectomy may be necessary for permanent pain relief. Block in the upper extremity syndrome includes the stellate ganglion and possibly some of the thoracic sympathetic ganglia. The lower extremity requires block of the second to the fourth lumbar ganglia inclusive.

The proper care of the patient with phantom limb pain is far from solved, since the fundamentals of disturbed function are still poorly understood. In the light of available facts and clinical experience, interruption of sympathetic pathways offers the greatest reward in the elimination of phantom limb pain despite the fact that the illusion of the absent limb will remain as a painless perception.

Fig 37 —Ideal levels of amputation are determined upon the basis of functional use A *knowledge of the function of the limb, both with and without a prosthesis, and an ap* preciation of the kinesiology affecting the lever arm of the remaining limb segment are essential for proper understanding The levels at which function of the stump is most efficient are called the sites of election From the site of election proximally to the upper end of any limb segment, function progressively decreases

The accompanying diagram reveals the amputation sites in two categories

(1) *The amputation sites commonly used*
(2) Obsolete and occasional amputations

In the commonly used amputations, the heavy shading represents the ideal levels in diaphyseal amputation with the shading gradually lessening as the less satisfactory levels are encountered The end bearing amputations are restricted to small bony areas and are, therefore, not shaded in the drawing Each of these is described in detail later

The occasional amputations are those used under special circumstances by experienced amputation surgeons Many are as yet of experimental nature, and have not been proved

Obsolete amputations are those which have been demonstrated by past experience to be of little practical value These amputations will be mentioned in the text for the sake of completeness, with an evaluation of each procedure

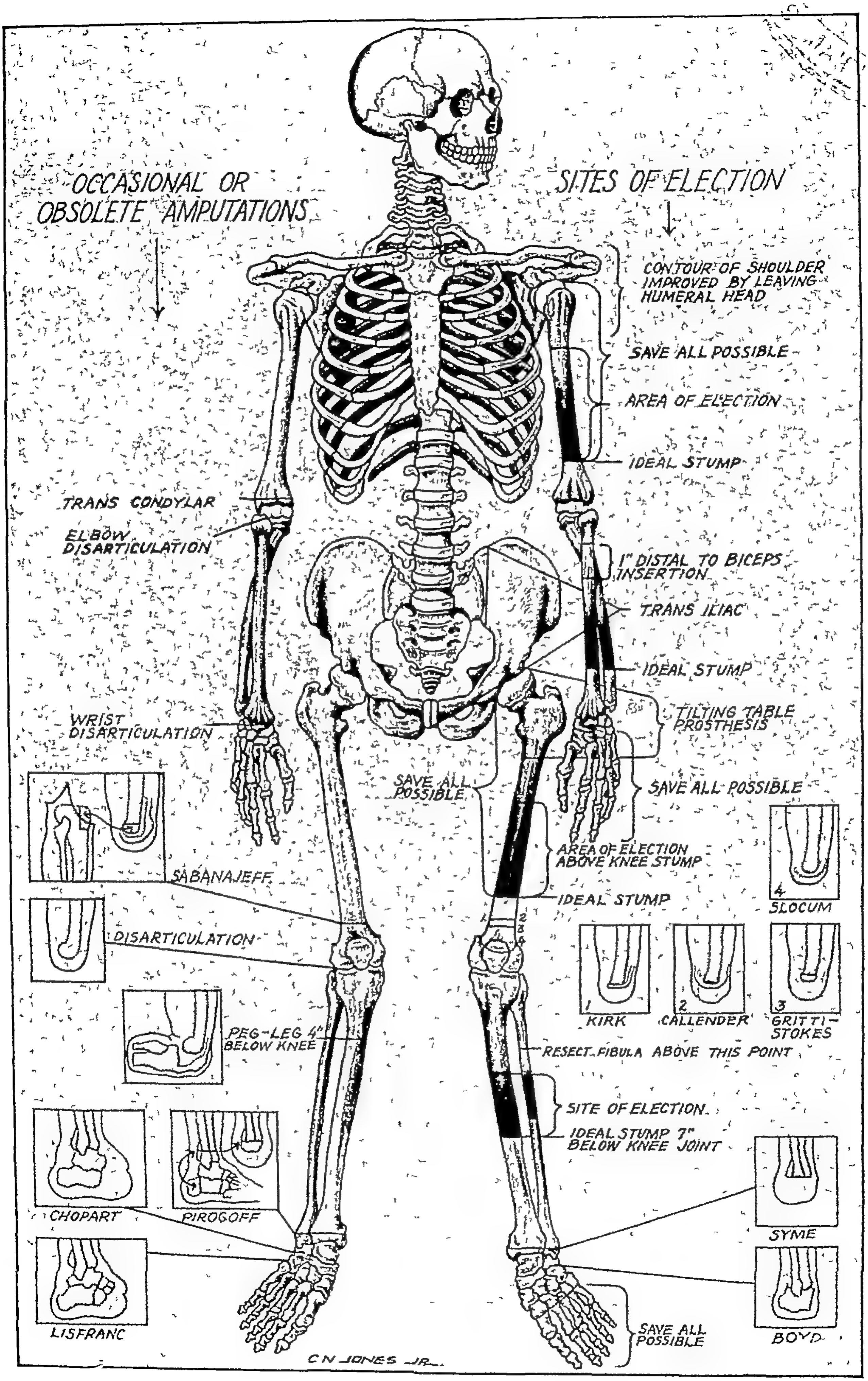

OCCASIONAL OR
OBSOLETE AMPUTATIONS
SITES OF ELECTION
CONTOUR OF SHOULDER
IMPROVED BY LEAVING
HUMERAL HEAD
SAVE ALL POSSIBLE
AREA OF ELECTION
IDEAL STUMP
TRANS CONDYLAR
ELBOW
DISARTICULATION
1" DISTAL TO BICEPS
INSERTION
TRANS ILIAC
IDEAL STUMP
TILTING TABLE
PROSTHESIS
WRIST
DISARTICULATION
SAVE ALL
POSSIBLE
SAVE ALL POSSIBLE
AREA OF ELECTION
ABOVE KNEE STUMP
SABANAJEFF
IDEAL STUMP
SLOCUM
DISARTICULATION
KIRK
CALLENDER
GRITTI-
STOKES
PEG-LEG 4"
BELOW KNEE
RESECT FIBULA ABOVE THIS POINT
SITE OF ELECTION
IDEAL STUMP 7"
BELOW KNEE JOINT
CHOPART
PIROGOFF
SYME
LISFRANC
BOYD
SAVE ALL
POSSIBLE
C N JONES JR

Fig 37

PART 3

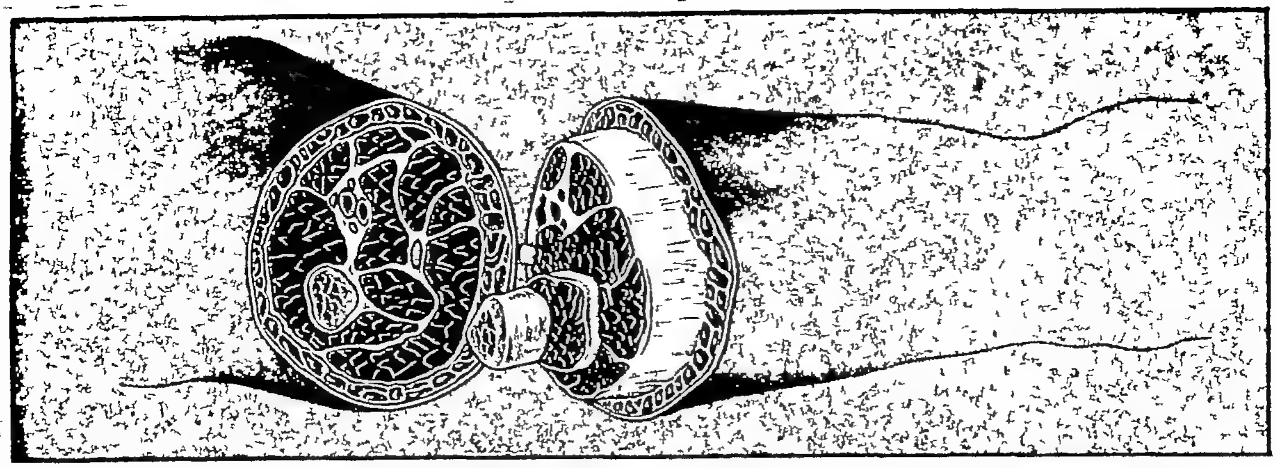
SURGICAL TECHNIQUES

V. OPEN AMPUTATIONS

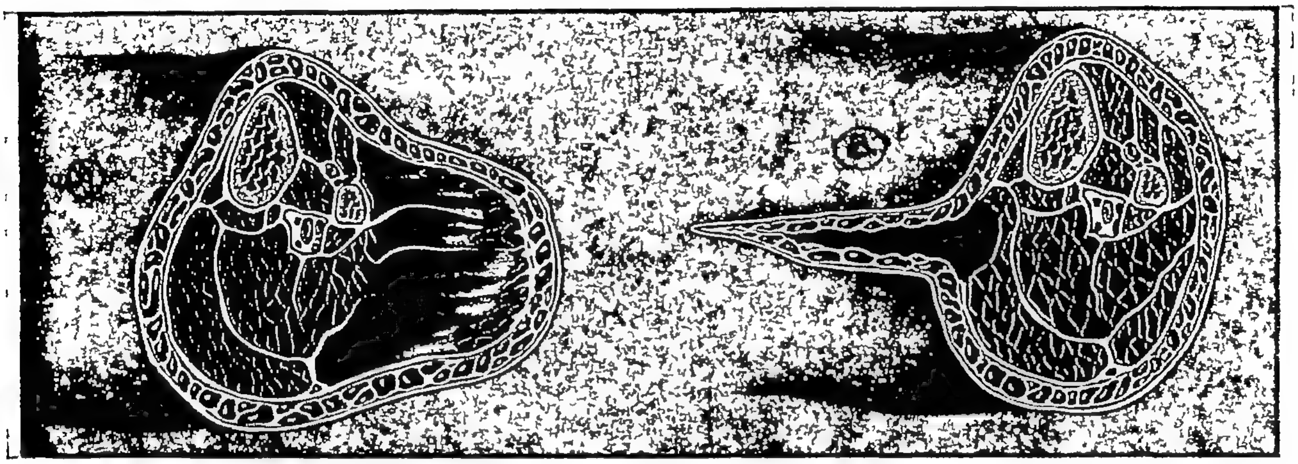
SURGICAL TECHNIQUES OF OPEN AMPUTATION

Open amputation, as the name implies, is one in which the skin is not sutured over the wound after the part is severed Its purpose is to eliminate active infection and afford adequate drainage for potentially infected tissues until they are healthy It is a preliminary step, always followed by final closure involving plastic repair, revision, or final type reamputation, when the structures have returned to normal and there is less danger of wound breakdown, and as such, it is performed instead of the closed amputation procedure whenever the surgical field is actively or potentially infected, and whenever the general condition of the patient does not predispose to sound healing of a closed surgical wound More specifically, it is indicated

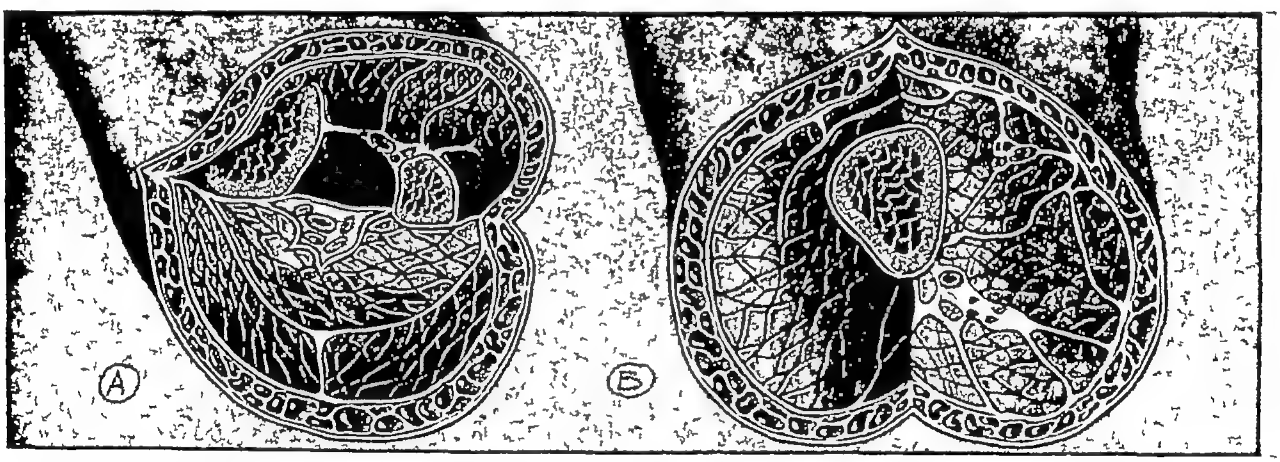
(1) In the fresh traumatic wound where foreign matter is present
(2) In the traumatic wound where unavoidable delay has made latent infection possible
(3) In an infected wound remote from the site of election when there is danger that infectious materials are passing upward through lymphatic channels Rather than chance infection of the final, closed amputation at the elective site, thorough drainage should be instituted by open amputation at a lower level
(4) Where trauma occurs at or near the sites of election with accompanying maceration and bruising It is not well to chance a closed amputation with other than normal tissue, and it will be found that greater length will be available for closure when the injured tissues have drained and edema has subsided
(5) In the presence of severe uncontrollable infection in which life is in danger, such as gas gangrene and severe septic arthritis
(6) In controllable infection where, in spite of further medical or surgical treatment, an extremity will remain useless
(7) In chronic, long-standing infection when local and general treatments are unable to control the effects of toxic absorption on heart, kidneys, etc



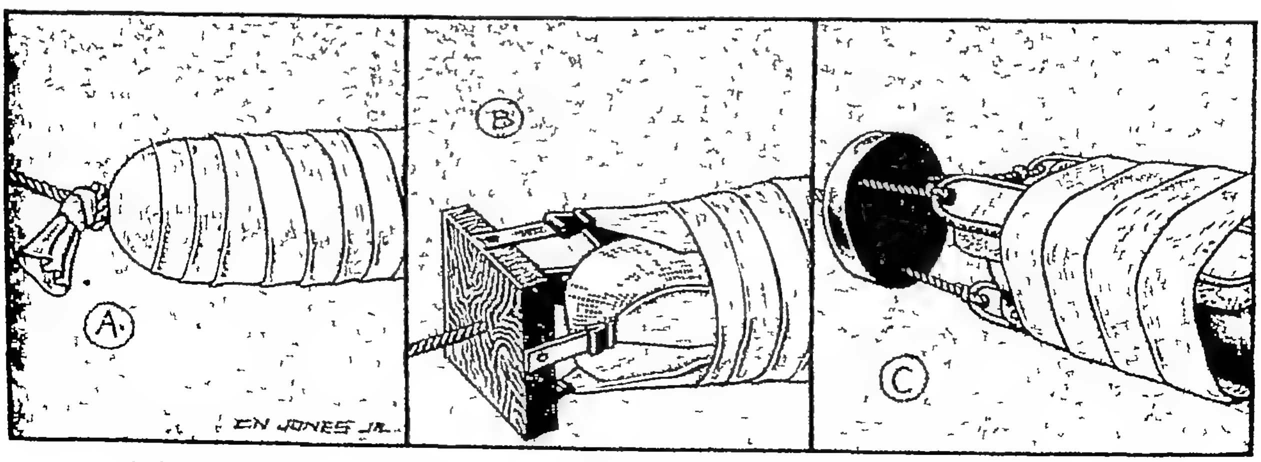
1 Circular type Circular skin section Section of muscles at the level of the retracted skin Section of the bone at the level of the retracted muscles



2 (A) Circular type with preservation of viable flap (B) Open amputation with incision for removal of necrotic muscle or drainage of infection



3 (A) Flap type below knee (B) Lateral flap type (sometimes used in above knee amputation to facilitate drainage)



4 Skin traction (A) Stockinet and skin glue (B) Adhesive tape (C) Rubber pad

Fig 38 —Open amputations

(8) Upon occasion, the general physical condition of a patient is such that he cannot withstand lengthy surgical procedure Where such is the case and amputation is indicated, open amputation may be the procedure of choice, even though no infection is present

(9) Infrequently, amputation must be performed in an isolated spot under poor surgical conditions Here again, open amputation is more readily carried out

(10) In war surgery, not only fear of infection from the nature of the wounds, but also the time interval between injury and treatment, and the difficulty in providing continuous treatment under battle conditions make open amputation the routine procedure

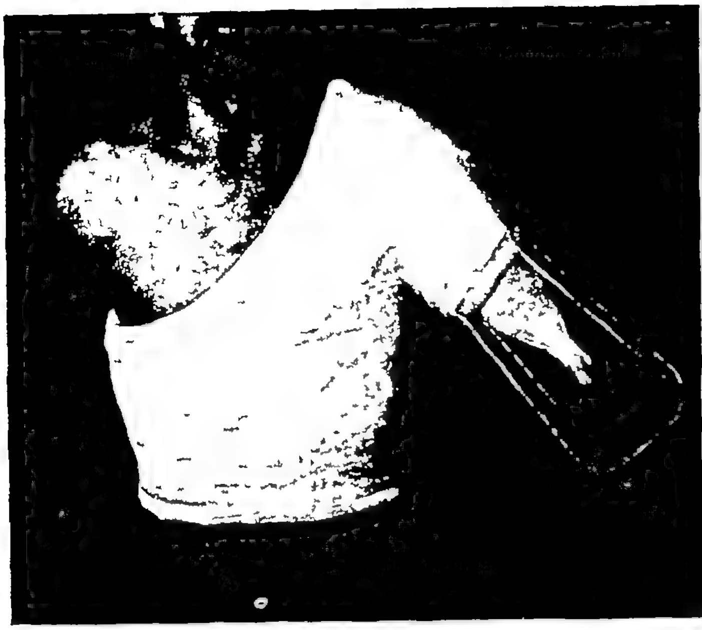
There are seemingly many methods for accomplishing the open amputation, but in actuality these may be divided into two main categories, each with several variations (1) circular open amputation (the term "Guillotine amputation," in common use as a synonym for circular amputation, will not be used in this text, it is a hangover from the days when the "Barber-surgeon" of the medieval wars would severe the limb with a single sweeping stroke of the knife, transecting all tissues at the same level, and I feel that it is misleading because of its connotation) and (2) open amputation with skin flaps Since either procedure is a preparatory step toward final closure, it must be performed so that all possible skin, soft tissues, and bone are preserved for the later formation of a final stump of ideal, or near ideal, length The incision, therefore, should be placed at the most distal point compatible with the elimination of all necrotic and infected material and with the promotion of thorough drainage, even though this should fall well below the site of election Thus allowance is made for any further débridement which may be necessitated by a recurrence of infection, and for the removal, at the time of final closure, of the scar formed by the healing of the open wound

Traction

In order to ensure all possible skin length for the later procedure, skin traction should always be applied in either type of open amputation When materials are available, this should be done at the time of operation, and should be maintained until the wound is closed or the skin is fixed to the granulating area with a dense band of scar tissue Skin traction accomplishes two purposes It draws the skin downward and over the open surface, and its tension tends to collapse soft tissue dead space and to limit further spread of infection If traction is not applied, and continued, recession of the skin will occur and the final result will be a stump with a large granulating wound capped by a protruding bone end To be effective in the flap method of open amputation, traction should be maintained until the wound is clean and ready for secondary closure In the circular method, it should be continued until the bone is well covered by scar or healthy granulation tissue, and the surrounding skin is fixed to the wound edge and is soft and free from edema When traction has been applied early and continuously, this process usually takes from four to six weeks In some instances, the traction will have succeeded in approximating the skin over the bone, and the terminus of the stump will be healed by scar Following are some methods of skin traction

1 Stockinet Traction

The leg is cleansed of all foreign material and painted with "skin glue" (Ace adherent) The coating should be fairly heavy in order to allow the



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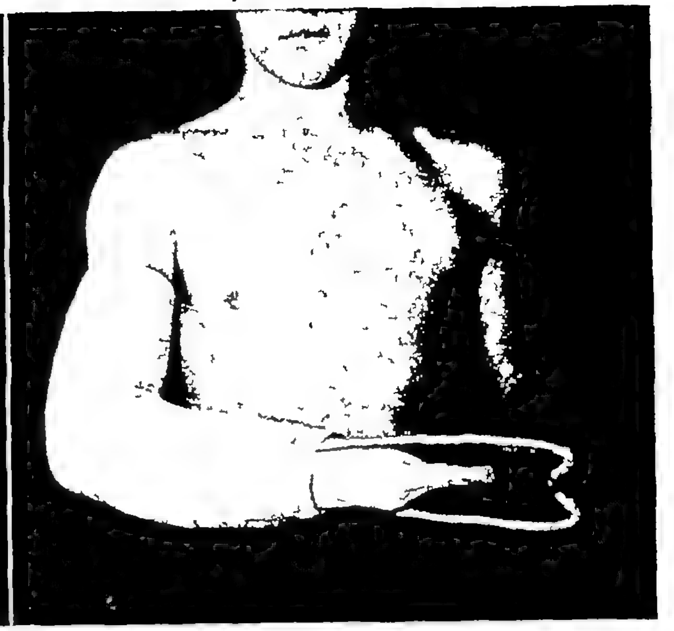

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Figs 39-42—Ambulatory traction, while by no means as effective as bed traction, is valuable where the amputee requires transportation for long distances over a considerable period of time to centers where definitive surgery can be done. Such traction is most conveniently of the "rubber band" type. It should exert continuous pull on the skin within the cast, and should be checked periodically to ensure its effectiveness and to guard against pressure areas. (Museum and Medical Arts Service, U S Army Medical Museum Fig 39 Neg No CA44199 Fig 40 Neg No CA44213 Fig 41 Neg No CA44196 Fig 42 Neg No CA44195

glue to penetrate the stockinet well. When the glue becomes "tacky," sterile stockinet of a size which will fit the limb snugly but not tightly is placed over the painted area and allowed to extend about eight inches beyond the end of the stump. Dressings, which have been previously applied over the wound, are tucked down to fit the inner contours of the stockinet. Should additional longitudinal wounds be present on the stump, the stockinet is split at those points and dressings applied. A single simple knot is now made in the stockinet as close to the stump end as possible, and any excess length of stockinet is removed. Moderate tension is applied to the stockinet, and an elastic bandage is wrapped about it; the protruding portion of the stockinet, drawn out under tension, makes it difficult to mold the elastic bandage perfectly over the stump end, but in so far as it is possible, this should be done. The elastic bandage, thus applied, serves three purposes: (1) fixation of the stockinet to the stump, (2) prevention of undue edema, and (3) molding of the stump to create a rounded contour of the terminal portion. The traction rope is now fastened just above the knot in the stockinet, serving to adapt the dressing still closer to the open wound. The rope is placed through a pulley at the end of the bed and weights are applied, starting with three pounds. This is later increased to between five and ten pounds, depending on the tolerance of the patient.

2. **Adhesive Strips**

When stockinet traction is not available, traction by adhesive tape strips may be used. Four of these of appropriate width to insure the greatest traction surface are placed longitudinally on the front, back, and sides of the stump, with the free ends extending well below it. A circular adhesive band is placed at the top of the strips and another at the stump end. The free ends are attached to a square block or ring, preferably by buckles to facilitate adjustment and change of dressings. The stump is then wrapped with elastic bandage to the level where the adhesive strips, due to tension, pull away from the rounded stump end. At this point, the bandage is carried back and forth over the end of the stump, inside of the adhesive strips. This is done under moderate tension, and the pressure is secured by final circular wrapping.

3. **Sponge Rubber Strips**

Recently, specially made sponge rubber strips which are nonirritating when applied directly to the skin have been used for traction. The strips are fastened to a heavy canvas backing and are affixed to the limb with elastic bandage. The canvas backing is tied by ropes to a round traction block, and thence to the pulley and the weights. This method will be of occasional value in late postoperative cases where frequent traction removal for dressings is indicated. However, the pressure necessary for fixation tends to be too greatly localized to make this a standard procedure.

Dressings

Unless contraindicated by severe infection, dressing of an open amputation should follow the fundamental principle that wound healing will proceed most rapidly under conditions of rest and least disturbance. Immediately following the operation a dressing impregnated with petrolatum jelly is applied to the wound to make future dressings of the raw, exposed surface less painful. Dry dressings are used to cover this, and traction and elastic bandaging follow. If prolific general oozing makes immediate traction seem inadvisable, elastic bandage under moderate tension should be wrapped about the stump, over the dry dressing, until traction is applied. The original dressing should not be changed

during the first week unless there is a positive indication to do so, such as excessive drainage, evidence of progressive infection, etc. Postoperatively the dressing may show evidence of serosanguineous drainage; this does not indicate removal of the primary dressing. On the other hand, marked frank bleeding soaking through the dressing is indicative of hemorrhage and should be investigated in order to determine whether or not secondary ligation is necessary. Usually the first postoperative dressing is quite painful. I have customarily used intravenous morphine or, in a few of the more apprehensive individuals, Pentothal Sodium to alleviate this pain. Subsequent dressings may usually be done without this extent of narcosis. The problem of dressing the stump while in traction is often puzzling when only an occasional open amputation is performed. During the change of dressings, traction is removed and the traction mechanism folded back proximally over the stump. The dressings are removed, exposing the granulating area. The wound and the surrounding skin are cleansed, and a fresh dressing of petrolatum jelly is applied. After the granulations become more mature and firm, the wound will no longer be painful, and a simple dry gauze dressing may replace the one of petrolatum jelly; drainage from the wound will be sufficient to prevent the adherence of the dressing to the granulations. Local chemotherapy has been found of no particular benefit to healing. If there is an abundance of local necrotic tissue, further débridement of the wound should be carried out. In some such instances, Dakin's solution will be required. In my experience this solution has been found far superior to other chlorine-liberating agents.

Circular Open Amputations

The circular open amputation is the method which should be used under all but special circumstances. Technically it meets all requirements. Wide-open drainage is afforded, dead space is eliminated, necrotic tissues are removed, osteomyelitis and soft tissue infection are avoided, and valuable bone length is preserved. It has the added advantage of speed and simplicity, and the technical knowledge required is not extensive provided sound surgical principles are adhered to. The technique of the circular open amputation is as follows. A tourniquet is applied, except in the presence of peripheral vascular disease. The incision is made at the most distal level at which there is no danger of extension of actual or potential sepsis. The skin is divided circularly to the deep fascia, and is allowed to retract (a distance of approximately one inch in most cases). The muscles are then divided at the level of the retracted skin. This is done slowly so that unequal retraction in different muscle groups will not result in an uneven wound surface. In the treatment of the bone no attempt is made to form a periosteal cuff since in an open amputation the loss of circulation, resulting from this procedure, predisposes to necrosis and sequestration of the bone end. Instead, a circular incision is made through the periosteum at the level of bone section to prevent the shredding of this structure when the bone is divided. This done, the bone is sectioned at the level of the retracted muscles. The major vessels are isolated and doubly ligated. Smaller vessels are tied or coagulated. Nerves are identified, drawn gently downward, sectioned, and allowed to retract upward above the exposed muscle surface. The wound is dressed with gauze impregnated with petrolatum jelly, and traction is applied. Open amputation is usually performed in cases where marked infection exists. This infection frequently disseminates upward through muscle planes and fascial spaces, forming infected pockets. These pockets must be drained and débrided of necrotic tissue by means of auxiliary, longitudinal incisions extend-

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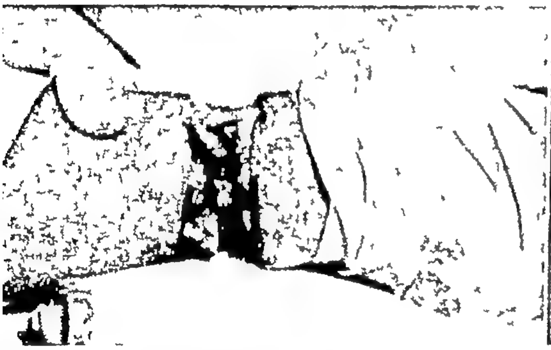
Fig 43—Traumatic wound of the lower leg and foot (Museum and Medical Arts Service Neg No D4471 U S Army Medical Museum)

Fig 44—Circular incision of the skin (Museum and Medical Arts Service Neg No CA44239 U S Army Medical Museum)



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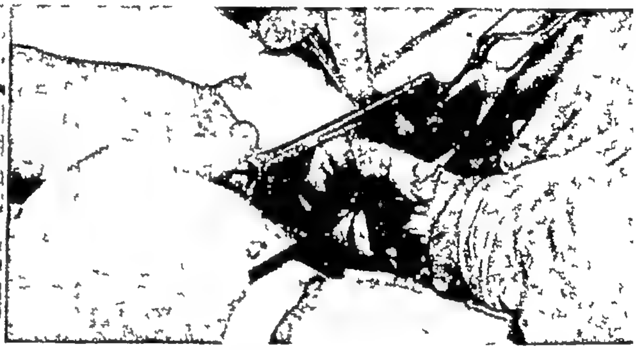

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Fig 45—Section of the muscles at the level of the retracted skin (Museum and Medical Arts Service Neg No CA44239 U S Army Medical Museum)

Fig 46—Section of the bone at the level of the retracted muscles Museum and Medical Arts Service Neg No CA44239 U S Army Medical Museum)

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Fig 47—Hemostasis (Museum and Medical Arts Service Neg No CA44239 U S Army Medical Museum)

Fig 48—Completed circular open amputation ready for the application of skin traction Note that all structures fall at the same level (Museum and Medical Arts Service Neg No D4471 U S Army Medical Museum)

ing downward to the open wound, the incisions are placed along the lateral aspect of the stump when feasible from the viewpoint of adequate drainage This position is preferable because anterior and posterior flaps are used in most instances in final plastic reconstruction of the open amputation stump An incision directly over bone should be avoided, for, even though healed by a fine scar, it is always subject to breakdown in a prosthesis

Fig 49—The unsatisfactory "Chop Guillotine" amputation in which all tissues are transected at the same level When the soft tissues retract, the bone projects beyond the muscles, and the muscles beyond the skin Such an amputation needlessly sacrifices valuable length within an area of election (Museum and Medical Arts Service Neg No D4456 U S Army Medical Museum)

Open Amputation With Skin Flaps

An open amputation with skin flaps is one in which the skin is cut in the formal flaps of the ideal amputation, so that it may be brought over the end of the stump, in secondary closure, after the danger of infection is past It provides covering for the open granulating wound and obviates the necessity of frequent and painful dressings, but in nearly all instances it affords no better drainage than the circular type of open amputation, with auxiliary longitudinal incisions when necessary, and it has two very definite disadvantages (1) it means an extra surgical procedure, since the secondary closure is only temporary and must always be followed by final definitive repair, and (2), of greater importance, it results in the loss of valuable length In this last respect, the deliberate formation of flaps means the loss of soft tissue and bone for a wedge of skin must be excised between the flaps in order to form them, and some bone length must be sacrificed in order that the skin may be approximated over the end of the stump during secondary closure, since effective skin traction is difficult to gain or maintain in the presence of flaps If, for any reason, such as severe infection, secondary closure is not carried out, this failure of traction to accomplish its purpose results in a condition which is definitely a hindrance to final repair, for it may be discovered that the flaps have become retracted, fibrotic, and fixed to underlying tissues by large masses of scar, or that they are still edematous at the time of final closure For these reasons, the formation of flaps is usually not indicated except (1) where tissue necessary for final repair lies distal to the site of a possible circular incision but can be conserved by means of a flap, (2) where flaps are formed during the course of débridement, or (3) in those rare instances where lack of facilities and transportation precludes proper dressing of the wound or the application of traction

In the open amputation with skin flaps, the flaps are formed in the same manner as those of a final operation (although it is well to allow about 30 per cent more skin than usual), and they are of three types: (1) single flap, (2) anterior and posterior flaps, and (3) medial and lateral flaps. A tourniquet is used and the surgical technique is essentially the same as in the circular type amputation with the exception of the skin incision. Since the purpose of the flap procedure is to facilitate temporary closure, meticulous pains need not be taken in trimming the muscles or caring for the nerves, and fine adaptation of tissues is not necessary.

Of the three types of flaps, the single and the anterior and posterior are the most commonly used. The single flap is quite frequently indicated on the basis of conservation, and is sometimes denoted as the "flap of necessity." In the single instance of disarticulation of the hip, the single flap is routinely the method of choice; this will be taken up separately later in this chapter. In all other cases, the single flap is a means of saving healthy tissue when it is available on only one side of an extremity. An example of this circumstance is a compound fracture in which the soft tissues on one side of the extremity are normal, while those on the other are hopelessly macerated. Were the circular incision to be used in this case, the normal tissue would be sacrificed, for the incision would have to be made above the level of injured tissue on the other side; but with the single flap, the circular incision is started and carried across the injured side at a level to débride all tissue affected by the trauma, and is then swung distally to form a flap of the tissue which has remained unharmed. This extra healthy skin may be of inestimable value when the time for final repair is at hand.

When secondary closure is anticipated and a double flap is indicated, the anterior and posterior type is more satisfactory than the medial and lateral. Although the purpose of the latter is drainage, this can be as readily accomplished in almost every instance by the circular incision with auxiliary longitudinal incisions, with a greater saving of tissue. It is never used in the upper extremity, and only rarely in the lower. It is definitely poor procedure in below-knee amputations for it leaves the tibia exposed and, therefore, subject to secondary surface infection, and it results in an anterior-posterior scar which is particularly bad from a prosthetic viewpoint in this area.

Open Amputation in the Hand and Foot

Open amputation in the hand and foot follows the basic precepts above: preservation of all possible tissue for final repair, and establishment of adequate drainage. However, there are peculiarities of these areas which demand variations in technique. In this small space a large percentage of tissue will be injured, and the surgeon must disregard the classic circular incision and divide the skin so that all possible healthy tissue will be saved. The skin cannot usually be drawn downward by traction in these areas, for the appendages are too small for the application of the apparatus and their skin and that of the metatarsal and metacarpal regions is fixed by fascial bands to underlying structures; it must, therefore, be cut so that it is of sufficient length to fall over the open wound without the aid of traction. It follows that the bone cannot then be sectioned at the level of the skin, as in the routine circular amputation, but must be divided well enough above this site to allow the skin to approximate over it in healing. The treatment of the tendons also is different. In the wrist, hand, ankle, and foot they are not deeply embedded in soft tissue, but glide within a mucous sheath. Also, in these areas they are near their termini and are, therefore, under slightly greater tension. Because of these two factors they are highly

retractable, and, in infected regions, particular pains must be taken to sever them so that they will not retract above the wound, carrying potential infection up into the tendon sheaths Should the tendon sheaths, or the deep fascial spaces of the hand or foot be already infected, drainage by auxiliary incision should be instituted in these structures at the time of open amputation Contrary to the course followed in other parts of the extremities, skin covering should be afforded the amputation wound at the earliest possible moment in order that scar tissue contracture may be minimized For this reason, as soon as the granulations within the wound are stable, the petrolatum packs are removed and the wound is treated by Dakinization or saline packs Then, when the bed of the wound is free of all necrotic debris, and the granulations are firm and cherry red, closure is effected

1 **The Hand.**

Open amputation of the fingers is usually carried out by circular incision The tendons are cut so that they will not retract above the edge of the wound, and the incision is then carried to bone The bone is resected to a point far enough above the skin so that that tissue will fall gently over the bone end A pack of gauze impregnated with petrolatum jelly is used, and dry dressings are applied Healing is by granulation and scar After infection is under control, approximation of the skin edges may be hastened by the use of narrow adhesive tape strips

The technique of skin incision may be varied by the use of oblique or single flap incision when this will preserve additional healthy tissue for final closure

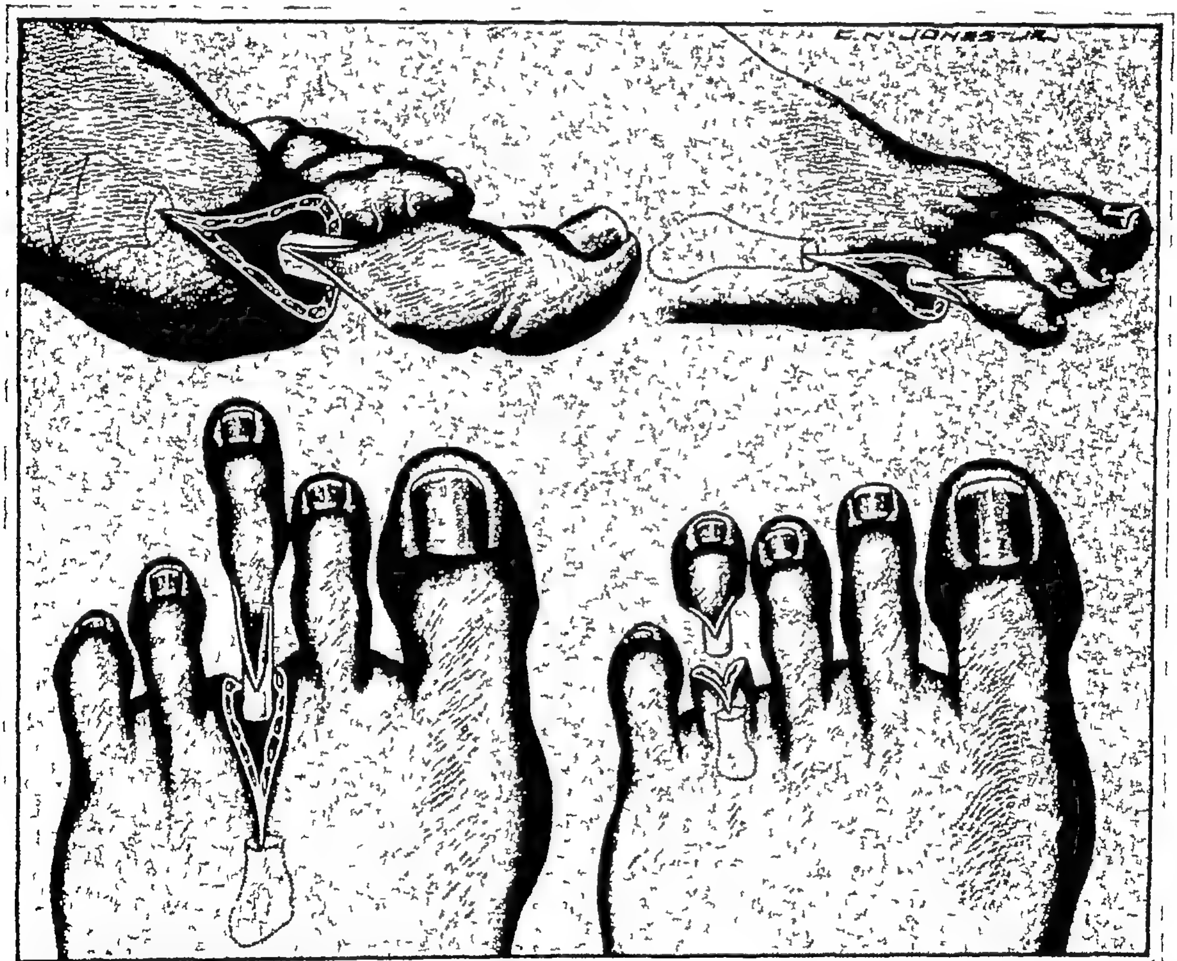
Open amputation through the metacarpals is carried out at the most distal level at which infection can be controlled It is done to rid the hand of a useless part and to supply adequate drainage of the infected area both to control the local infection and to prevent extension into the tendon sheaths and fascial spaces This site is selected for two reasons (1) The metacarpal bones are subcutaneous at this point and easily available, and (2) crippling scars of the palm of the hand and web space between thumb and index finger are avoided The dorsal racquet incision is employed This starts on the dorsal aspect of the metacarpal bone of the involved finger and proceeds to the level of the metacarpophalangeal joint It then swings obliquely downward through the ulnar web space and crosses the palmar aspect at the level of the proximal flexion crease of the finger Thence, it passes through the radial web space and obliquely upward to join the original incision at the level of the joint The metacarpal bone is freed from its bed and sectioned at a point where infection is controllable and thorough drainage is afforded The tendons are cut so that they do not retract beyond the wound Necrotic tissue and periosteal tags are débrided from the wound Bleeding is controlled, and the wound is packed with petrolatum gauze and a dry dressing is applied An anterior plaster splint is applied to the forearm and hand for immobilization When the wound is ready for closure, it is effected in the thumb, index, and little finger metacarpals by using lateral pressure, or by adhesive tape strips, in the middle and ring finger metacarpals where the tissues cannot be collapsed, a thin, split thickness, free skin graft is used

2 **The Foot**

The foot, due to the protective covering of the shoe, is less frequently the object of trauma severe enough to demand amputation Within this area the most frequent indication for amputation will be minor trauma or slight infection which is made ominous by the presence of vascular disease This condition

which does not complicate the picture in other extremities, demands special evaluation by the surgeon, and a deviation from the usual procedure It will be discussed in detail separately In those cases where open amputation is indicated to control infection and the area is not affected by vascular disease, the technique is as follows

Open amputation of the toe A towel clip is placed in the toe to facilitate handling The traditional circular incision is made at the most distal level at which infection can be controlled, and the tendons are isolated The extensor tendon is sectioned with the toe in extension, and the flexor tendon with the toe in flexion to ensure the minimum retraction of these structures The incision is carried to the bone, which is sectioned high enough above the level of the skin to allow later approximation of the lips of the wound without tension Hemostasis is secured and the wound is dressed



1 OPEN AMPUTATION OF THE TOES AND METATARSALS

Fig 50—Open amputation of the toes and metatarsals

Open amputation through the first metatarsal employs a racquet incision This is begun on the medial aspect of the first metatarsal at the most distal level to accomplish the control of infection It is drawn distally along the shaft to the neck of that bone, where it is swung dorsally to skirt the base of the great toe in the web space It is carried across the plantar flexion crease and thence upward to join the original incision over the metatarsal neck The incision is carried to bone The metatarsal is sectioned at the lowest level at which infection

can be curbed. Tendons are cut so that they will not retract above the wound. All necrotic material is débrided, and drainage is effected for sepsis in the fascial spaces. The wound is then packed with petrolatum gauze and a dry dressing is applied. Skin cover is afforded when the granulations appear healthy and normal.

Open amputation through the fifth metatarsal is the counterpart of open amputation through the first metatarsal, carried out, of course, on the lateral aspect of the foot. The same technique is followed throughout.

Open amputation through the second, third, and fourth metatarsals is accomplished through a racquet incision with an added longitudinal plantar incision. It starts on the dorsal aspect of the metatarsal to be excised at a level to ensure the check of infection. It passes distally to the neck of that bone, at which point two companion incisions swing to the web spaces on either side of the toe. There they pass along the base and thence across along the plantar flexor crease, to converge at the midline. From this site a longitudinal incision courses upward along the plantar aspect of the metatarsal to the proximal level of the original incision. The incision is deepened to bone, the tendons are severed with care, and the bone is sectioned at the most distal level at which control of the infection can be expected. Excellent through-and-through drainage is afforded by this incision. The wound is packed with gauze impregnated with petrolatum jelly and dry dressings are applied. Closure is undertaken when the granulations are normal.

Open Amputation of the Forefoot in the Presence of Peripheral Vascular Disease

As was noted above, peripheral vascular disease is the greatest single etiological factor in amputation in the forefoot. Consideration will here be given to certain departures from the general rules which must be made in the presence of this condition with its circulatory impairment and subsequent gangrene and infection. Where vascular disease is found, the blood supply is so poor that the tissues are unable to throw off the threat of infection, and even a trivial ailment or trauma, such as athlete's foot or a minor cut, may become invaded with severe, uncontrollable infection. Such a condition usually arises at or near the tip of the foot, but with blood supply impaired by vascular disease there is little or no hope of restricting it to that level. When this is the situation, no infection is too small to be an indication for amputation. If the sepsis is minor and does not extend far into the fascial spaces above the metatarsophalangeal joint, it may occasionally be brought under control by amputation and wide open drainage at that level; if it has reached out beyond, there is little hope of saving the foot or the leg, and amputation should be undertaken above the knee. Since experience has proved that there is a high incidence of failure of amputation through the forefoot in the presence of vascular disease, the surgeon, before he makes such a choice, should be convinced that circulation is sufficient to allow healing. At the risk of repetition, I wish to state again here that there must be normal pedis dorsalis pulse, good nutrition and normal skin temperature, normal color on dependency of the extremity, and absence of ischemic pain. If these criteria are met and amputation through the forefoot appears feasible, certain general rules must be adhered to:

(1) The level must be high enough to insure adequate blood supply to sustain the remaining tissues.

(2) Drainage must be wide, thorough, and dependent when the patient is in the recumbent position.

(3) Tendon sheaths and fascial spaces must be widely exposed to the limit of the infected area, and all necrotic tissue must be removed
(4) A tourniquet should never be used
(5) The skin should be long enough to fall together without tension as healing takes place
(6) Buerger's exercises followed by early ambulation are essential in the older age group

This point cannot be stressed too strongly Wherever amputation is to be carried out in a region affected by peripheral vascular disease, it is *imperative* that excision extend into an area at which comparatively normal blood supply is present, and that drainage be decidedly more radical than under normal conditions

Open amputation of the toes in the presence of vascular disease involves much more extensive excision of both bone and tissue than open amputation under other conditions Medial and lateral flaps are used, rather than circular, in order to afford dependent drainage in both the recumbent and dependent positions, and to avoid contractures of the adjacent web spaces during healing A first incision starts on the dorsum of the toe at the level of the web space and swings distally over the ulnar side of the toe a distance of a little more than half the diameter of the toe, and then passes upward and around to end at the midline of the toe on the plantar surface at the level of the flexor crease A second incision on the radial side of the toe is identical Since no tourniquet is used, bleeding is arrested with the progress of the surgery Tendons are divided, care being taken to avoid their retraction above the wound level The incision is now carried to bone and the proximal phalanx is sectioned at its base, rather than at any more distal point The flaps are allowed to heal by scar

Open amputation through the metatarsal bones in the presence of peripheral vascular disease is indicated when osteomyelitis has reached above the level of the web space, when gangrene extends high on the toe, and when any infection has invaded the fascial spaces of the foot, for, with impaired blood supply, lesser drainage will not suffice This operation is the same in execution as open amputation through the metatarsals when uncomplicated by vascular disease, except that excision and drainage are more radical, and no tourniquet is employed The skin and other tissues are incised at a point overlying the base of the metatarsal, and the bone is sectioned at that level Without the use of a tourniquet, hemostasis must be accomplished as the surgery proceeds Skin cover should be provided as soon postoperatively as possible

Open Disarticulation

Open disarticulation is an open amputation through a joint It is undertaken when amputation is indicated and the joint level is the most distal point at which sepsis can be eliminated or controlled It is simple, rapid, easily performed, and leaves tissues above the joint undisturbed for use in later final revision The nature of the skin about the joints, however, is different from that overlying the shaft of a long bone It has marked elasticity, is thin in type, possesses a poor layer of subcutaneous fat, and has a relatively poor blood supply It retracts to a greater degree, and is frequently anchored to the underlying fascia This condition is found to be more marked on the flexor surfaces than on the extensor Due to these characteristics of the skin and due to the configuration of the metaphyseal flare over which it must be drawn, traction is notoriously ineffective at the joint levels With this in mind, the skin should be left longer than would normally be anticipated, and

a slightly oblique rather than a purely circular incision should be made in order that the skin over the flexor surface may be longer than that over the extensor surface. (This is not to be confused with the single flap discussed previously in this chapter. The single flap is made up of a circular incision on one hemisphere of the limb and a classic flap on the other. An oblique incision is a circular incision done at an angle.) If the skin is not cut longer and an oblique incision is not used, all skin will retract above the muscle and bone levels, and too large an area of granulation will result, requiring greater excision and resulting in undesirable loss of length at the time of final revision.

1. **Open Disarticulation of the Knee Joint**

The general indications for open disarticulation, noted above, apply at the knee joint. However, severe septic arthritis is found more often in this joint than in any other, and will be the most frequent indication for disarticulation of the knee. Such a procedure should never be performed where adequate drainage of the knee joint would bring the infection under control, nor where the infection has already established itself in the fascial planes of the thigh. As was stressed above, the usual circular incision does not provide adequate covering in disarticulation because the skin in the popliteal region will retract markedly despite intensive traction. The usual picture of an old open disarticulation of the knee depicts the femoral condyles exposed and covered with granulation tissue, and the skin retracted high in the popliteal region. Whenever time and the condition of the patient permit, the outer parts of the femoral condyles should be resected so that the bone is roughly tubular in shape, being reduced to the approximate size of the area immediately above the condyles. In this way, traction will be made much more effective.

TECHNIQUE. The oblique incision starts anteriorly at the superior border of the tibial tubercle and passes circumferentially about the limb with the skin being one inch longer at the posterior popliteal aspect than it is on the anterior side. It is carried to the deep fascia, and the skin is allowed to retract. The patellar tendon and the fascia about the anterior aspect of the knee are next divided. The tibial and fibular collateral ligaments are severed. The hamstring muscles are divided through their tendinous portion and allowed to retract. The posterior fascia is divided, exposing the popliteal artery and vein. These two structures are isolated, clamped above and below the point of severance, and sectioned. The proximal ends are doubly ligated with plain No. 1 catgut sutures. The posterior tibial and peroneal nerves are isolated, drawn down gently, severed, and allowed to retract in their beds. The posterior capsule of the knee joint is now sectioned, completing the disarticulation. At this time, if conditions are favorable, the condyles should be removed. Cartilage need not be removed from the distal femoral surface, but the suprapatellar bursa should be investigated and adequate drainage instituted. The tourniquet is removed and hemostasis is secured. The wound is dressed and traction is applied.

2. **Open Disarticulation of the Ankle Joint.**

The ankle length stump does not lend itself well to a prosthesis unless a Syme amputation can be performed. The basic requirement for this operation is adequate healthy plantar skin with which to cover the weight-bearing stump end. In the presence of active or potential sepsis there is seldom a sufficient amount of this tissue which is free from infection, and, therefore, the ankle level will not be anticipated as the final site of amputation. On this basis, open disarticulation at the ankle joint is rarely indicated. Infrequently, the surgeon

will find himself in the presence of partial traumatic disarticulation of this joint In this unique instance if the condition of the patient is poor, severance may be completed at this level This is done more in the sense of débridement than of disarticulation, and is purely a timesaving measure Under all other circumstances, a circular open amputation at the level of the distal one-third of the leg is preferable to open disarticulation In either case, later reamputation at the ideal level must be undertaken Severance in the shaft of the leg still allows sufficient length for this procedure, affords skin of better quality, and is not complicated by the flare of the malleoli which makes traction virtually useless

3 **Open Disarticulation of the Elbow Joint**

In open disarticulation of the elbow, as in that of the knee, the skin retracts excessively and to a greater extent on the flexor surface than on the extensor To counteract this the incision begins one inch below the olecranon tip on the extensor surface and circles the forearm obliquely, having as its most distal point the level of the insertion of the biceps tendon on the flexor surface The skin is reflected upward and all soft tissues are cut at the level of the elbow joint to free the forearm The nerves are drawn down and sectioned, the major vessels doubly ligated, and general hemostasis is secured The wound is dressed and traction is applied The condyles need not be removed in elbow disarticulation for they are smaller at this level than at the knee and have a deeper layer of overlying tissue Traction is fairly effective in this area

4 **Open Disarticulation of the Radiocarpal, Intercarpal, or Carpometacarpal Joints**

Open disarticulation of the wrist is performed when a serviceable stump clothed with good palmar skin can be anticipated following subsequent final repair If such a result cannot safely be assumed, disarticulation should be abandoned for open amputation of the forearm at a level immediately above the styloid processes of the radius and ulna The term, open disarticulation of the wrist, in reality is a general one applied to the levels of the radiocarpal, intercarpal, and carpometacarpal joints Regardless of which level is selected, the ideal incision is circular in type and lies one and one-fourth inches below the distal transverse skin crease on the anterior aspect of the wrist, for this will afford enough good palmar skin to cover the stump end following definitive surgery Atypical flaps may be required through circumstance the long palmar flap in the absence of dorsal skin, the thenar flap in the absence of hypothenar skin, and the hypothenar flap in the absence of thenar skin When the skin incision has been completed and the flaps reflected to the desired level, section of the deeper structures is begun At the radiocarpal joint, the wrist is placed in ulnar deviation and the soft tissues including the joint capsule are sectioned starting at the radial side Tendons are severed with care to ensure minimum retraction and to lessen the danger of upward spread of infection through their sheaths The radial and ulnar arteries are ligated before section since they are extremely retractable and difficult to locate once severance has been complete, absolute hemostasis is secured A petrolatum jelly gauze dressing is applied to the open wound and covered with plain gauze dressings and the whole is covered with an elastic bandage When severance is performed at the carpometacarpal and intercarpal joints, the procedure is the same with the exception of the treatment of bone, there, it is more difficult to follow the joint lines because of their irregular contour It is frequently simpler to section the bones and joints transversely as a group with saw or bone-biting forceps since the end result is much the same and the bony contour smoother

5 Open Disarticulation in the Hand and Foot

Disarticulation in the true sense of the word is never done in either the hand or the foot when infection, actual or potential, is present The hyaline articular cartilage, because of its poor blood supply, tends to undergo rapid degeneration and necrosis when in a septic area This condition prolongs and aggravates the infection and predisposes the excision of the cartilage In the hand or foot this excision is carried out at the subchondral level in order that freer drainage of the capsular recesses may be established Therefore, open amputation at the subchondral level is actually done in the hand and foot in place of open disarticulation

6 Open Disarticulation of the Hip

Open disarticulation of the hip is indicated in severe trauma where the limb has been destroyed at this level, or in those traumatic cases where repair will result in a useless limb or inadequate thigh stump (If any workable stump can be saved, disarticulation should not be considered) Other indications are (1) fulminating gas infection extending upward toward the hip joint, particularly where high compound fracture of the femur is associated with anaerobic infection, (2) acute septic arthritis not controllable by wide drainage, (3) chronic septic arthritis in which drainage has not controlled the toxic absorption and the patient has become cachexic and bedridden, with secondary changes showing in the kidneys, liver, and other organs This last is often accompanied by osteomyelitis of the upper end of the femur, or irreparable sciatic nerve lesion, and these added complications lend weight to the decision for removal of the limb

Technique Hip disarticulation differs greatly from disarticulation at the end of a long bone, for its objective is not to pull the skin down over a metaphyseal flare and form a covering for the end of a bone, but rather its aim is to collapse the dead space created by the removal of the femur The skin is fashioned to form one long posterior flap slightly greater in length on the medial side The incision is carried out in the following manner The femoral artery is palpated as it passes below Poupart's ligament An anterior longitudinal incision is then made, starting at Poupart s ligament and extending downward a distance of three to three and one-half inches The wound is deepened to expose the femoral artery and vein, which are isolated, doubly ligated, and sectioned The femoral nerve is sectioned and allowed to fall back in its bed The incision now swings downward across the inner surface of the thigh to a point approximately three inches below the attachment of the adductor tendon to the pubis (In large individuals this part of the incision should be extended farther distalward in order to create a longer flap with which to cover the open wound when final plastic repair is undertaken) The skin incision now crosses the posterior aspect of the thigh, swinging gently upward as it reaches the lateral portion, to cross the femur at the inferior tip of the greater trochanter It then passes around the anterolateral aspect of the thigh with a very slight upward curve to join the original incision The muscles are divided under moderate tension The leg is first placed in adduction, and the skin is retracted above the greater trochanter The muscles are then removed from this structure by severing them at their tendinous insertion The anterior thigh muscles are sectioned at the level of the skin as far over as Poupart's ligament The leg is now placed in abduction, and the adductor muscles are divided near their insertion The capsule covering the femoral head, neck, and acetabulum is now largely exposed It is divided circumferentially, and the head of the femur is dislocated from the acetabulum by abduction, external rotation and extension The ligamentum teres, which connects the femur and the head of the acetabulum, is cut A large

amputation knife is now placed between the femur and the gluteus maximus and drawn downward and outward to the distal end of the skin flap where it severs the posterior thigh muscles transversely In this way a thin layer of muscle is retained to line the posterior flap and aid in its blood supply Large, bulky, redundant muscle masses should not be allowed to remain, for they will become infected and undergo scar tissue degeneration which will make difficult later plastic repair The extremity is removed, and the open wound is inspected It is carefully débrided of all necrotic tissue and exposed capsular and ligamentous tissue within the wound Sinus tracts are excised Hemostasis is secured Dakinization of the wound will rarely be required if the débridement is thorough and all necrotic tissue and ligamentous structures have been removed A dressing impregnated with petrolatum jelly is placed in the open wound No traction can be applied, but elastic bandage is used and directed so as to bring the posterior flap upward over the dressing As infection subsides, the flap will heal over the wound, starting at the posterior fold and forcing the dressing out When the dressing is no longer necessary within the wound, the edges of the flap may be approximated to the lip of the wound by adhesive This method allows optimal drainage, thus avoiding infected pockets within the closed wound, and insures minimal scar tissue to be excised at the time of final repair

7 Open Disarticulation of the Shoulder

Indications for open disarticulation of the shoulder are the same as those for open disarticulation of the hip, and the same principle is followed—the filling of a cavity rather than the extension of skin over a long bone The disarticulation is executed in much the same manner also except that, instead of a flap being formed, a circular incision is made This is done at the level of the deltoid insertion The deltoid muscle is preserved and its attachment to the skin left undisturbed, this prevents excessive retraction on the deltoid surface The long muscles of the arm are sectioned transversely at this level, and the pectoralis major, latissimus dorsi, and short rotators are divided at their humeral insertions The major vessels are sectioned and doubly ligated, and the nerves are drawn down, sectioned, and allowed to retract The humerus is now completely exposed It is freed from the shoulder joint by section of the capsule, and all necrotic, tendinous, and fascial remnants are removed from the wound It is packed with petrolatum gauze and covered by dry dressings After the acute reaction and the infection subside, lateral pressure is applied by elastic bandaging, and the deltoid muscle and overlying skin are collapsed into the cavity made by the removal of the head of the humerus and by the retraction of the axillary skin The lips of the wound meet in rough approximation As in the open disarticulation of the hip, open drainage is afforded and the pack is forced out by healing In this case, adhesive is not necessary to hold the deltoid skin in place while healing by granulation and scar takes place

Open Amputation in Osteomyelitis

Chronic bone infection (osteomyelitis) does not always predicate amputation However, it does demand it when the general health or life is endangered by the constant absorption of toxic products, or when only a useless extremity will result from continued orthopaedic treatment When the involvement of the extremity is of recent origin or it is limited in extent, the technique differs little from the ordinary circular type of open amputation When infection has been extensive and of long standing, the picture is greatly altered The generalized fibrosis which has resulted as a reaction from the infection involves all

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Figs 51 and 52—When open amputation is carried out in extremities subject to extensive osteomyelitis, the area affected by the sepsis should be completely eliminated Since both the skin and the underlying soft tissues are involved in cicatrix, their retraction is not anticipated, therefore, the skin is incised circumferentially, the muscle is sectioned just above the level of the skin, and the bone is divided slightly above the level of the muscle (Fig 51 Museum and Medical Arts Service Neg No D44244 U S Army Medical Museum Fig 52 Walter Reed General Hospital Neg No 4814 2)

Fig 53—Don't section muscle and bone above the level of normal skin retraction with a view to allowing the skin to fall over the end of the stump, for this means the loss of valuable length Rather, cut all structures so that they will fall at the same level after retraction, and apply skin traction to pull the skin down sufficiently to afford adequate integument (Museum and Medical Arts Service Neg No CA44360 U S Army Medical Museum)

Don't undertake primary closure of an open amputation

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Fig 54—Breakdown of damaged tissues and subsequent loss of length will frequently follow primary closure of open amputation, as it did in this case (Museum and Medical Arts Service Neg No CA44495 U S Army Medical Museum)

Fig 55—Even though primary closure of an open amputation may be successful, as it was in this case, the resultant stump is always poorly shaped, due to the fact that definitive surgery cannot be performed upon traumatized tissues, and final plastic repair must always be undertaken (Museum and Medical Arts Service Neg No CA44529 U S Army Medical Museum)

Fig 56—Don't perform *early* secondary closure of an open amputation, for, not only is the shape of the stump poor, the scar unsatisfactory, and the likelihood of breakdown great (as indicated by the small granulating area in this case), but also definitive surgery is always required By the use of skin traction and proper preparation of the tissues until they return to normal, an additional operative procedure is avoided and valuable bone length is saved (Museum and Medical Arts Service Neg No CA44428 U S Army Medical Museum)

Fig 57—Don't perform extensive plastic procedures where the stump will remain unsatisfactory following surgery The multiple pinch grafts used in this patient, who lost his limbs through gasoline burns, lacked sensation, normal skin texture, and ability to withstand trauma Since this stump would not stand up under normal use even without a prosthesis, further definitive surgery had to be carried out to ensure normal skin coverage Reamputation was performed at the mid thigh level on the right, and hip disarticulation on the left (Walter Reed General Hospital Neg No 4522 1)

Fig 58—Don't apply skin grafts to an open amputation These serve only to negate the effectiveness of skin traction and thereby result in loss of stump length When such a graft is present, the stump should be reconverted into an open amputation by excision of the graft and its circumferential cicatrix, and traction should be applied to draw the normal skin down over the end of the stump (Museum and Medical Arts Service Neg No CA44434 U S Army Medical Museum)

the tissues the skin becomes thickened, fibrotic, and adherent to the underlying muscle and fascia, the muscle, itself, loses most of its normal texture and becomes largely replaced by fibrous tissue, the blood vessels are fragile and friable, the nerves become anchored fast in their beds, the bone itself becomes sclerotic and may have adjacent sequestra and periostitis In these advanced cases, open amputation is performed in the following manner The most distal point at which the bone is healthy is chosen as the level of amputation However, the skin is not incised at this site for it has lost its resilience and, even with intensive traction, cannot be drawn down to cover the stump In order to avoid a stump with a large granulating area and protruding bone end, the skin is cut at a point well below the intended bone level The incision is made in the usual circular fashion to the level of the deep fascia Due to edema and fibrous infiltration, and because it is adherent to the underlying tissues, the skin does not now retract as it normally would Therefore, it must be dissected free to the line of amputation and reflected slightly above this while muscle severance is carried out by transverse section If the muscle is bound by scar, it should be cut at the level of amputation, if it is found to have some contractibility, it should be sectioned slightly below The periosteum is then divided circumferentially at a point slightly above the muscle level, and the bone is sectioned with an amputation saw Since the nerves are usually caught in the fibrous scar and cannot be drawn down in the normal manner, they are isolated, dissected upward in their beds for a centimeter or two above the muscle, and severed Great care must be taken with the hemostasis in this fibrotic muscle area Bleeding is usually troublesome in these cases since blood vessels are difficult to secure with a hemostat, and stick ties must usually be relied upon rather than the hand tie or electric coagulation After the tourniquet it removed and all remaining bleeding points eliminated from the field, the wound is dressed and traction is applied

PRELIMINARY PREPARATION OF THE OPEN AMPUTATION STUMP FOR FINAL REPAIR

Following open amputation there must be a period of preparation in which to achieve ideal conditions for final repair, for that is an elective procedure and, as such, should not be performed until the general condition of the patient is good and the surgeon has sufficiently healthy tissue and a clean surgical field with which to work The care and procedures to be discussed in this section are undertaken during that preliminary preparation period, and are completed before final repair is begun

The general physical condition of the patient should be such that his resistance to infection will be at a maximum This is most imperative in the face of final repair of an open amputation, for the field is always potentially infected due to the presence of granulation and scar tissue Though the initial amputation will eliminate the primary sepsis and thereby effect great improvement in the general health of the patient, there still may be anemia, hypoproteinemia, and avitaminosis, in addition to occasional concurrent infection or general disease The patient should be thoroughly checked for these conditions, and they should be eliminated as far as possible It is also important that the blood levels be restored to normal Preferably, large amounts of blood and plasma are used to accomplish this rather than reliance on oral medication and time Once the level has been obtained, which can be done rather promptly in this way, the patient should be given all possible help in maintaining it by the administration of high caloric, high protein diet with supplementary iron and vitamins A healthy mental attitude should be instilled in the patient during this preparatory period in order to eliminate as far as possible the uncertainties of the

future He should be educated as to the nature of the amputation and the prosthesis and should be helped to understand the limitations of his condition and to realize the effect of the correct mental attitude on his social readjustment Above all, he should be fully aware of the time element involved before his complete rehabilitation

The stump should present a perfectly normal surgical field If all has gone well with open amputation surgery and postoperative care, the stump will be free from excessive edema and infection, and its terminus will be covered with skin healed by scar, or with skin and a small area of firm granulation tissue For such a stump the preliminary preparation is simple steps should be taken to eliminate edema entirely so that the skin is soft and pliable, attention should be given to the surface of the skin, which should be cleansed thoroughly, and any dermatitis eradicated, the granulating area should be washed clean of any film of necrotic debris so that it is cherry red in color, and exercises should be instituted to restore muscle tone and maintain muscle balance When these basic measures have been completed, and the general health of the patient is at its best, the time for final definitive surgery has arrived

Unfortunately, all cases do not follow such an uneventful course Sometimes, because of inability on the part of the surgeon, ideal open amputation surgery and postoperative care have not been carried out At other times, complications unforeseen or due to circumstances beyond the control of the surgeon have developed In such instances, special treatment, in addition to the care given the ideal stump, will be required to get the field in readiness for final repair Not infrequently this treatment may involve further surgical procedures

Basic Preliminary Preparation of the Stump

Elimination of edema is essential in any stump before final amputation, for skin that is edematous has inadequate circulation and therefore heals poorly and is a potential culture for infection Bed rest and elevation, bandaging and whirlpool bath are employed to achieve this Of these, bed rest and elevation are particularly important Since many amputees have been ambulatory for a time following open amputation it is often difficult to convince them that they should become bed patients It is imperative to do so, however, for dependent edema with congestion of skin and muscles usually occurs during ambulation, in fact is inevitable if any type of infection, superficial or deep, is present If the patient is allowed to remain ambulatory, even though the stump is bandaged conscientiously, it may require months to restore the tissues to normal, whereas, if bed rest and elevation are enforced, a week or two will usually accomplish this end Bandaging should be carried out in conjunction with bed rest, for it not only aids in eliminating edema but helps to mold the stump It applies the principle of mild compression of the tissues by an elastic bandage, which prevents the accumulation of new fluid deposits and helps in the milking out of the soft tissue accumulation The technique is described elsewhere in this text It should be stressed, however, that the pressure thus applied should be greater on the distal end of the stump than on the proximal portion If this is not so, its action will be that of a mild tourniquet, impeding venous return and further increasing stasis and edema The pressure exerted should be continuous, which often necessitates the changing of the bandages several times a day This is particularly true during the ambulatory period The whirlpool bath, used in conjunction with the above methods, is fairly effective in reducing edema, for it improves circulation, but it should never, of course, be employed where any deep infection is present

Care of the skin involves the cleansing away of surface pathogens, restoration of normal skin texture through the elimination of all crusts desqua-

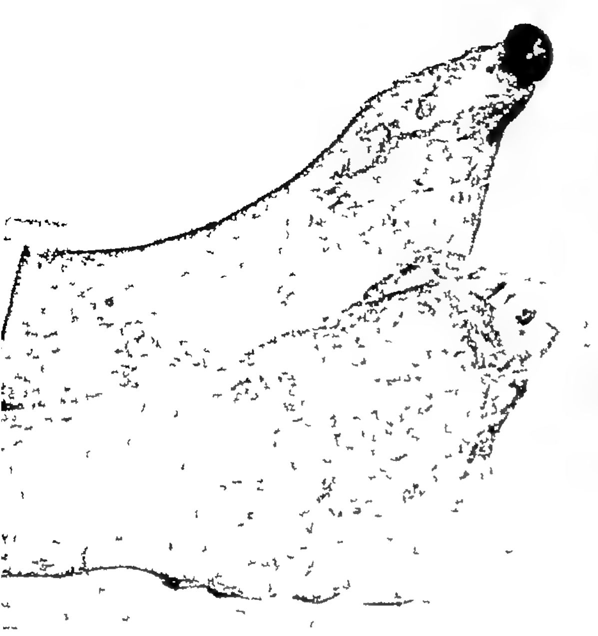

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Fig 59—Amputation of the forefeet through frostbite The gangrenous toes have been removed at a previous débridement The protruding bone is necrotic, granulation tissue is dirty, skin has poor circulation and is not cleansed The protruding bones must be removed, granulations cleaned, and the circulation returned to normal before final type amputations can be performed, in this instance Symes (Walter Reed General Hospital Neg No 4329 2)

Fig 60—Traumatic amputation of the forefoot Necrotic remnants of skin remain over the wound which is covered by dirty granulations and projecting bony fragments (Walter Reed General Hospital Neg No 5009)

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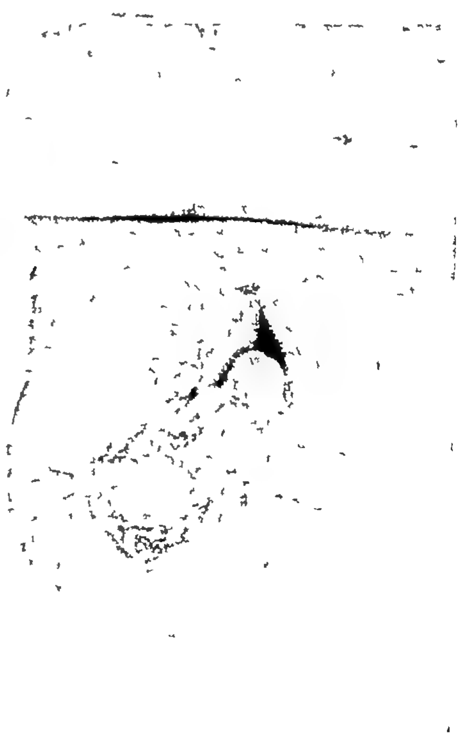

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Fig 61—Below knee amputation after traction has been removed The border of the granulating area is fixed by scar, the granulations themselves are dirty, and the surrounding skin is dirty but healthy (Walter Reed General Hospital Neg No 4302 1)

Fig 62—Above knee amputation after traction has been removed The remaining granulating bed is boggy and edematous, especially in the crevices at the upper border of the wound (Walter Reed General Hospital Neg No 4360 2)

mating skin, fats and oils, and complete control of any dermatitis The most troublesome of the skin infections is eczema This condition is due to the infectious discharge from a draining wound and is most likely to occur where there are deep skin folds over the draining area Absolute cleanliness must be maintained in all folds and sulci, and the skin should be bathed with alcohol, frequent change of dressings is necessary to eliminate the accumulation of secretions When the deep infection has subsided, the eczema will clear up A second very troublesome skin infection is folliculitis, which is particularly common in hairy individuals Its control is dependent upon cleanliness Alcohol baths and alcohol packs should be employed locally, and adhesive tape should not be used on the stump end In cases where the reaction is extensive, hot saline packs should be applied Abscess formation in the skin is most often secondary to folliculitis and is usually found to be primarily staphylococcic in origin It should be treated by incision and drainage

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Fig 63 —Open amputation of the upper end of the thigh after removal of the first dressing Much superficial necrotic tissue and debris are present which will disappear after further bandaging and preparation (Museum and Medical Arts Service Neg No 298 U S Army Medical Museum)

Fig 64 —Open amputation below the knee covered with skin graft The graft must be removed and traction applied to gain more skin length before final revision is undertaken (Museum and Medical Arts Service Neg No CA44533 U S Army Medical Museum)

following localization by massive hot packs Occasionally, an erysipeloid infection will occur in a stump General reaction is much like that of true erysipelas, with elevation of temperature, and general symptoms such as malaise, prostration, headache, and gastrointestinal disturbance The stump is a dull red color, with a well-defined line of demarcation, and the skin is hot painful, and edematous The nature of this condition is unknown, but is probably on a streptococcic basis As treatment, penicillin in large doses should be administered,

and massive wet packs should be applied to the inflamed area. Since it is a diffuse infection, incision and drainage are not indicated for they would only serve to aggravate the condition.

Care of the granulating area of a healthy stump, free from deep infection, is relatively simple. It is cleansed by whirlpool bath or by application of saline packs. Where surface infection seems severe enough to warrant it, or considerable necrotic debris is found, one-half strength Dakin's solution may be employed, followed by saline packs. Occasionally, ultraviolet and zinc iontophoresis will aid in improving the granulating bed. In the past, cultures were taken from every open granulating wound before final surgery was performed. This procedure has proved of no particular value because the wound invariably contains a mixture of many pathogens even when the granulations are in excellent condition. The exposure of the granulating bed is, of course, responsible for these many secondary invaders. Pyocyaneus is sometimes found and is one organism which must be thoroughly eliminated before any plastic procedure is undertaken, failure to do this will result almost uniformly in breakdown of the wound. The presence of tetanus and anaerobic organisms is less alarming. The tetanus can be controlled by tetanus antitoxin or toxoid injections prior to operation, a desirable prophylactic measure in any event, and the anaerobic organisms cannot flourish unless sealed away from the air. Despite the most diligent preparatory cleansing of this granulating area, the seeds for reawakening past infection may remain. The surgeon can only rely on the appearance of the tissue itself. When this is firm and cherry red, he may consider it ready for final closure.

Muscle training should be carried out during the period of preliminary preparation to insure that the muscles which power the stump will be as strong as possible after final surgery has been completed. Most of these will have undergone considerable atrophy, and if the patient is to use the stump and prosthesis well, they must be re-educated and strengthened. This process will take a long time if an active and regular regime is not followed. The power of the muscles of the body as a whole should be ascertained by muscle check, and they too should be kept fit by muscular re-education, as described in the chapter on physical medicine.

Prevention of contracture is simple, the important step being the assurance that proper bed posture is maintained, for, when it is faulty, adaptive contractures of the soft tissues may result.

Care of Complications in Preliminary Preparation of the Stump

Infection

All too frequently, sepsis will still exist within the stump, even though open amputation surgery and immediate aftercare have been conscientious. If this infection is draining out through the granulation area, that tissue will require more strenuous cleansing than that noted above. Its surface must be débrided of all necrotic elements, exposed fascia and remnants of tendon, and wide-open drainage must be instituted. Dakin's solution and saline packs should then be used on débrided areas and infectious pockets.

If drainage or edema persists during the period of preparation, the following complications should be looked for.

Cellulitis is a diffuse regional inflammation of the soft tissues and should be treated by means of massive wet packs until the temperature subsides and edema is gone.

Abscesses should be localized by hot wet packs, and thoroughly drained.

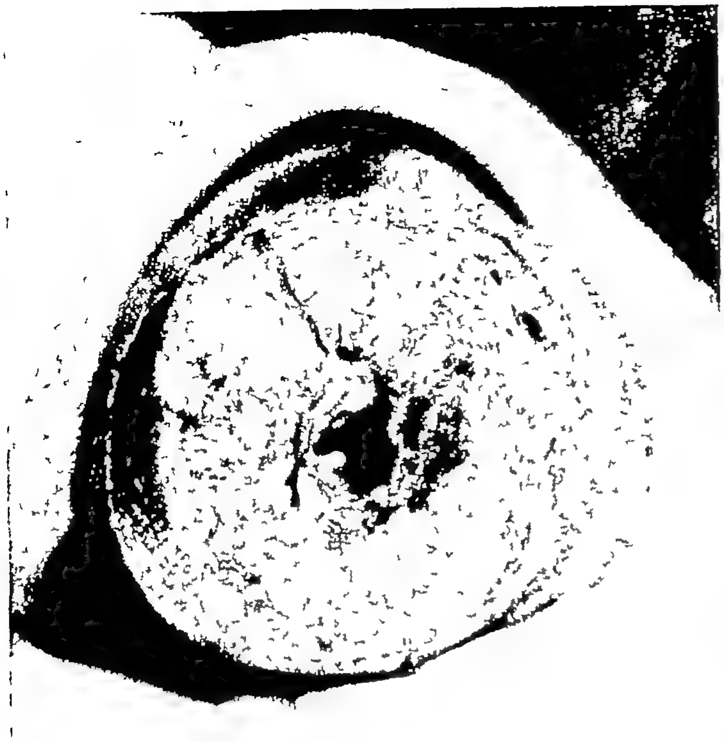

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Fig 65—The end of an open amputation stump following rupture of an abscess Surgical drainage was required, and was followed first by a petrolatum gauze pack, and later by the usual preparatory measures (Walter Reed General Hospital Neg No 4241-1)

Fig 66—Secondary gas infection developing in an open amputation This would never have occurred had the original amputation been carried out sufficiently high

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Fig 67—Draining sinus of a below knee stump following incision from origin to outlet and use of a petrolatum gauze dressing (Walter Reed General Hospital Neg No 4505 1)

Fig 68—Same case after further preparation for final surgery by means of bandaging and whirlpool baths (Walter Reed General Hospital Neg No 4257 2)

Fig 69—Terminal ring sequestrum due to osteomyelitis of the end of the stump and removal of a ring of periosteum from the distal end of the bone at the time of open amputation Sequestrectomy was required

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Fig 70—Low grade infection at the end of the stump with sequestration of a terminal fracture fragment Sequestrectomy was required

Fig 71—Osteomyelitis of the distal end of the radius and ulna with sequestration and new bone formation Incision, drainage, and sequestrectomy were carried out

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Fig 72.—Massive sequestrum with surrounding involucrum at the distal end of an open amputation stump Resection of the distal end of the femur was performed above the level of infection

Fig 73.—Osteomyelitis with sinus formation in a compound fracture of the surgical neck of the humerus in an above elbow stump The choice here lay between further amputation of the arm and surgery directed toward the elimination of the osteomyelitis The latter course was followed

Fig 74.—Osteomyelitis in combination with septic arthritis of the hip in an above-knee amputation stump The necrotic femoral head was removed, the hip drained, and the Colonna procedure carried out after elimination of all infection

Gas infection, or other anaerobic infection, if of a localized type, should be treated by wide incision and drainage with muscle resection If of the fulminating type, amputation at a higher level above the gas infection is indicated A great deal of clinical judgment will have to be exercised in these cases to avoid endangering the patient's life, and if there is any question at all as to the efficacy of local surgery, it should be abandoned for higher amputation

Draining sinuses are a frequent finding in the open amputation stump X-ray will aid in determining whether they arise from septic soft tissue or septic bone Those caused by the latter will be discussed in the following paragraph on osteomyelitis Persistent draining sinuses originating from soft tissue infection usually denote the presence of foreign bodies such as nonabsorbable suture implanted clothing, and organic or inorganic materials Simple curettement or irrigation of the sinus tract is often performed in these cases, but such procedures are of little avail, even when the irrigation is done with the most recently developed chemotherapeutic solutions, such as penicillin I have seen many sinuses treated by these means, and the results have been almost routinely unsatisfactory, temporary healing may take place, but usually at the time of final repair drainage will recur, or infection, dormant within the sinus walls, will flare up The only effective way to eliminate a draining sinus is a two-stage procedure carried out in the following manner The sinus tract is traced from its mouth to its source and its whole extent opened wide through normal skin (The use of methylene blue to outline the sinus at the time of surgery affords little help, but, to the contrary, often discolors the tissue so that it is difficult to follow the course of the infectious process) The focus of infection is excised and any irritants are removed The tract, itself, is then débrided and wide-open drainage is instituted Occasionally, in the hands of an experienced surgeon, all dead space may be collapsed at this point, and closure effected The safest course, however, is to allow the sinus to heal by scar and granulation tissue while it is still exposed, and then proceed to the second stage, the excision of the scar bed to healthy tissue, the collapse of dead space, and closure

Osteomyelitis in the open amputation stump is usually of external origin, a direct result of previous inadequate care of a wound Within the stump this bone sepsis is most often caused by incomplete débridement, remnants of foreign matter, or uncollapsed dead space At the end of the stump, it is due to the consummation of secondary closure when infectious material still remains within the wound In either case, x-rays should always be taken to determine the extent of the involvement Sometimes bone abscesses will form, and these should be opened and drained More frequently, a draining sinus will establish itself, communicating with the open wound This should be treated in accordance with the methods explained above, but in the presence of osteomyelitis special care should be taken to ensure (1) wide exposure, (2) freshening of the bone to healthy osseous tissue, and (3) maintenance of adequate drainage Dead space should always be avoided, for it is a potential abscess or draining sinus If it cannot be collapsed immediately, it should be laid open to the surface of the stump by a longitudinal incision If the treatment for osteomyelitis is being carried out where a secondary closure has been effected, the stump should be opened widely through the old suture line

Sequestra represent bony fragments, varying in size from minute particles to massive pieces of bone, which have become devitalized through loss of blood supply usually because of infection or trauma They may lie within the continuity of bone, may have been cast off and rest in the soft tissue near the bone, or be at the cut end of the bone In x-ray appearance, a sequestrum itself looks more opaque than normal bone, while the granulating area around it appears as an area of decreased density When the sequestrum lies above the bone end

the usual cause is osteomyelitis of external origin, the result is persistent bone infection, abscess formation and draining sinus, the fate of the sequestrum is either that it remains in situ until it is surgically removed as a part of the surgical treatment of osteomyelitis or is cast off through a draining sinus Treatment is directed toward early removal of such a necrotic fragment of bone and surgical eradication of associated infected bony or soft tissue foci When the sequestrum is terminal, it is usually a fracture fragment which has become devitalized or a "ring sequestrum" Fracture fragments are often allowed to remain at the time of open amputation if that procedure is carried out through a fracture site which is within or immediately distal to the area of election, for there is the possibility that they will unite with the shaft of the bone and restore the full circumference of the bone for later repair Sometimes however, the periosteal blood supply has been interrupted through the original trauma, or the fracture site becomes infected through the open amputation wound and the fragment, rather than uniting with the bone, becomes devitalized and forms a sequestrum Treatment consists of removal through the open wound during the preliminary preparation period "Ring sequestra" form in response to the combined loss of periosteal blood supply, because of stripping of the periosteum, and the intramedullary blood supply, because of thrombosis of the vessels lying in the distal end of the intramedullary canal When such a combination occurs, the terminal one-fourth to one-half inch becomes devitalized, then necrotic, and eventually separates itself from the healthy bone above In the past such sequestra were seen frequently, due to the custom of removing a band of periosteum one-fourth to one-half inch in width from the terminal end of the bone during the course of open amputation, now, since that custom has become obsolete, they seldom are found unless the stripping has occurred through trauma at the time of the original injury

New Bone Formation

New bone may form along the shaft of the bone, extend below the bone level, or infiltrate the muscles or other soft tissues It is caused by irritation from trauma or by infection If the cause is infection, the treatment and elimination of this will result in cessation of further new formation As to the new bone itself, it is not disturbed during preliminary preparation unless it is found to be a focus of active infection

New bone along the shaft of the bone is usually the result of periostitis (inflammation of the periosteum) brought about by an irritation of the periosteum above the level of amputation, such as (1) bruising or other trauma at the time of accident, (2) injury through stripping, reflecting, or careless handling at the time of open amputation, or (3) infection of bone or soft tissue in juxtaposition to periosteum

Extensions of periosteal new bone at the end of a long bone result from irritation of the periosteum at the site of osteotomy They are unfledged ossification of remnants left when the periosteal sleeve has not been sectioned sharply and evenly They need not be excised unless infected, for they are pliable and will conform readily to the molded contour of the stump

Distal extensions of new bone which have become mature are called spurs Seen in an x-ray, spurs are more dense and more distinct in form than mere periosteal new bone, and appear to have the structure of normal bone They usually lie well within the contour of the stump for they have been subject to the pressure of bandaging during their formative period along with other tissues They do not, therefore, interfere with further bandaging or traction which might be necessary during the preliminary preparation, and need not be removed at this time

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Fig 75—Bony spur at the tip of an open amputation below knee stump This is a nonseptic, new bone formation probably arising from a periosteal tag

Fig 76—Cross union of the distal ends of the tibia and fibula following ossification of a periosteal remnant

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Fig 77—Periosteal new bone formation at the site of amputation for compound fracture

Fig 78—Massive new bone formation about the end of the bone, in the periosteum, and in the soft tissues at the side of the stump (myositis ossificans) This developed as a reaction to low grade infection

Fig 79—New bone formation as a reaction to infection Note the periostitis at the sides and ends of the bones

Diffuse infiltration of new bone formation through the muscles and other soft tissues unrelated to the periosteum is known as myositis ossificans It is a sequela of trauma or infection of the tissues themselves These bony masses are left undisturbed during the preliminary preparation period except for the elimination of the causative factor if this be infection Should it become apparent later that they will interfere with function, they should be removed at the time of final repair

Insufficient Skin

A lack of sufficient skin for final repair or revision of the open amputation is a complication indeed, for it means that valuable bone length will have to be

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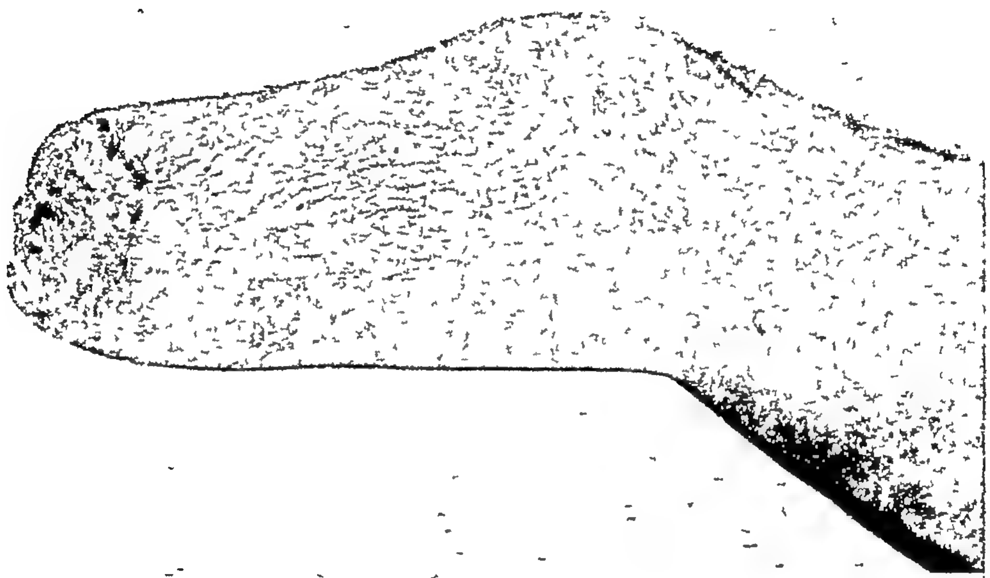

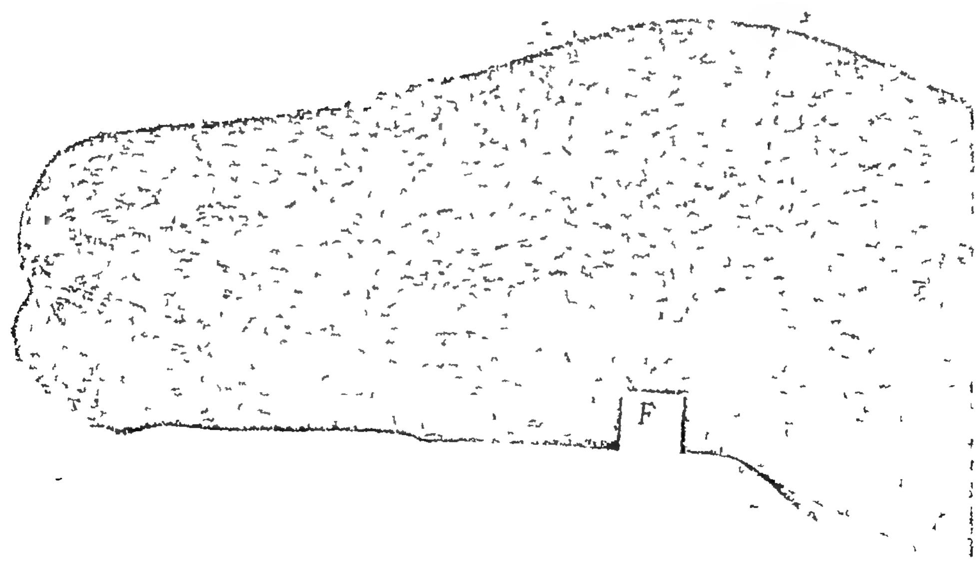

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Fig 80—Skin graft over the terminus of a below knee open amputation stump. (Walter Reed General Hospital Neg No 4193 2)

Fig 81—Same case after the excision of the skin graft and the application of skin traction Note that by this procedure sufficient skin length was gained that simple excision of the terminal scarred area and plastic repair were all that was required at the time of final closure (Walter Reed General Hospital Neg No 4420 3)

CONDYLECTOMY

(A step in the preparation of open disarticulation of the knee, undertaken when end bearing at this level is anticipated)

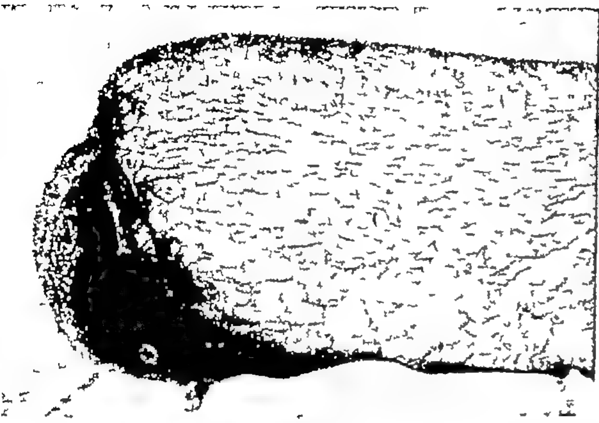

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Fig 82—Open disarticulation of the knee Note that traction has failed to provide adequate skin covering (Walter Reed General Hospital Neg No 4316 1)

Fig 83—Same case after condylectomy and skin traction (Walter Reed General Hospital Neg No 4429 2)

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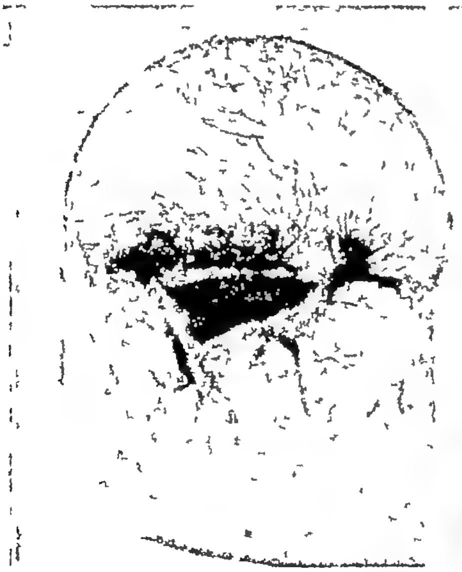

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Figs 84 and 85—Side and terminal views of a second case following condylectomy and application of skin traction Final repair required only excision of the scar and resection of a minimal amount of bone (Walter Reed General Hospital Neg No 4323 2, 3)

Fig 86—X rays of the same case showing the configuration of the femoral condyles following condylectomy Surgery is directed toward eliminating any bony flare which may act as a barrier to downward traction rather than toward creating any specific form of the bone (Walter Reed General Hospital Neg No 4584 A 2, 5)

sacrificed, and stump length thus lost, to accomplish satisfactory closure It is usually the result of (1) failure to apply any traction, (2) failure to apply traction soon enough, (3) too early cessation of traction, or (4) ineffective traction because of the manner of application or because of unideal surgical procedures prior to application

Such a situation should be corrected during the period of preliminary preparation by reapplying skin traction and continuing it until the skin has been stretched to its fullest extent This is not as simply done at this stage as it is immediately following open amputation, but often requires one of the following surgical steps in order that traction may be effective

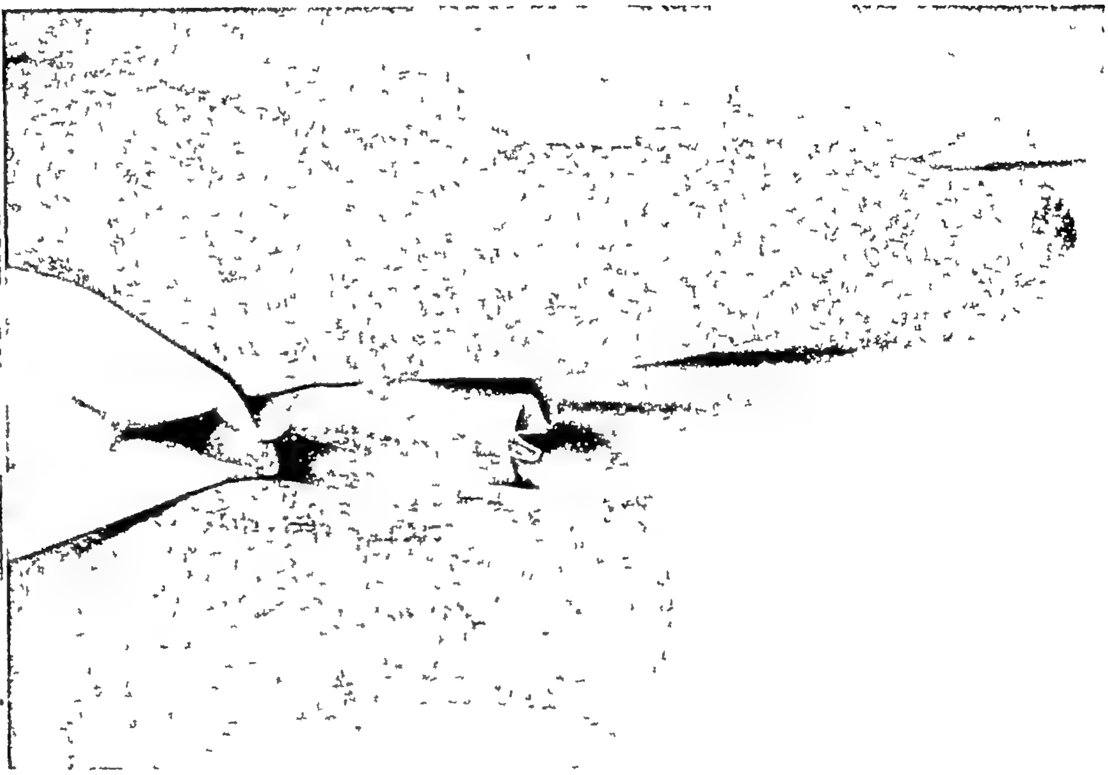

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Fig 87 —Terminal view of a knee disarticulation following condylectomy, and before the completion of traction (Walter Reed General Hospital Neg No 4326 3)

Fig 88 —Same case after final repair of the stump (Walter Reed General Hospital Neg No 4551 2)

Excision of the terminal cicatrix affords the release of skin which has become fixed to granulation tissue before being drawn down sufficiently Traction will be of no avail until this heavy band of scar has been removed This is carried out in the following manner The normal skin immediately adjacent to the terminal scar binding the skin to the granulating area is incised to the layer of the deep fascia The terminal cicatrix is excised, and all redundant granulations are trimmed and necrotic tissue débrided The skin is undermined between the layers of the superficial and deep fascia to a point where this plane is well defined (This may be an inch or more above the incision) Skin traction is then applied, preferably with stockinet traction, until maximum skin length has been achieved

Excision of skin grafts Upon occasion, a skin graft, usually of the split-thickness type, is applied to the terminal end of the open amputation stump as a form of secondary closure This procedure is to be condemned, for a graft over the terminus of the stump precludes the use of traction following the original

amputation, and must always be excised later so that the skin can be drawn down for final repair, thus necessitating additional surgery (Exception in the hand and foot, and in these areas alone, the skin graft is an accepted method of secondary closure, for there, due to the nature of the soft tissues, traction is never applied When used in these regions, there is no need to remove it until final repair) When a skin graft is to be excised during the period of preliminary preparation, the incision is made through normal skin immediately adjacent and carried to the level between the superficial and deep fascia The graft, itself, is then removed through the scar base upon which it rests, and the skin is undermined for one to two inches to ensure its mobility Traction can then be applied in the usual manner

Partial removal of the femoral condyles (condylectomy) will, under ideal circumstances, be performed at the time of open disarticulation of the knee, in order that traction may be carried out successfully during the postoperative period However, conditions are not always favorable at that time, and the frequent picture before final repair is that of a stump end with skin retracted high in the popliteal region, with condyles exposed, and with an excessive area of scar and granulation tissue This condition in the ankle, wrist, or elbow is of little importance, for, in any of these instances, reamputation is routinely anticipated at a site of election considerably proximal to the distorted area After disarticulation of the knee, however, reamputation is not always expected If the patient is young and capable of weight-bearing, a prosthesis will be worn in the future, and this is best adapted to the stump in which the bone level is just above the condyles Obviously, if there is hope of weight-bearing, the poor stump described above must be revised so that there will be sufficient skin available for final repair Although less soft tissue can be gained under these circumstances than would be under the conditions attendant formal closed amputation, satisfactory integument can usually be provided when traction is used, and appropriate surgical intervention is employed to make it effective Since the skin in the popliteal region is highly intractable, no effort is made to draw it downward at this time, but it is left fixed to its scar attachment so that it will not migrate upward and leave even less posterior tissue available for later repair That on the anterior aspect, however, is freed from underlying tissues by the excision of the anterior band of scar and, after the removal of the flare of the femoral condyles, is drawn down by traction The removal of the metaphyseal flare not only makes the downward pull of the skin easier, but also eliminates much of the pain which usually attends skin traction in this area The technique of the condylectomy itself is as follows The incision starts at the mid-point of the lateral aspect, immediately proximal to the scar border of the granulating area, and follows this border over the top of the knee joint to the midpoint of the medial aspect It is deepened into the knee joint in the original incision The anterior skin and underlying extensor mechanism are then reflected upward by dissecting the adhesions in the suprapatellar bursa, and the bone is thus exposed anteriorly The patella is excised The femur is now sectioned transversely with a saw through the expanded portion of the condyles This level is chosen to ensure adequate bone length for further excision or trimming during final revision All projecting corners of bone which might act as an obstacle to downward traction on the skin are quickly removed with side-biting forceps, so that the femur now has roughly the same circumference at this site that it has in the supracondylar region The severed condyles are now reflected downward and posterior tissues are sectioned If the skin extends below the bone level, the knife is turned downward and these tissues are cut obliquely, the skin being severed at the proximal border of the granulating area On the other hand, if

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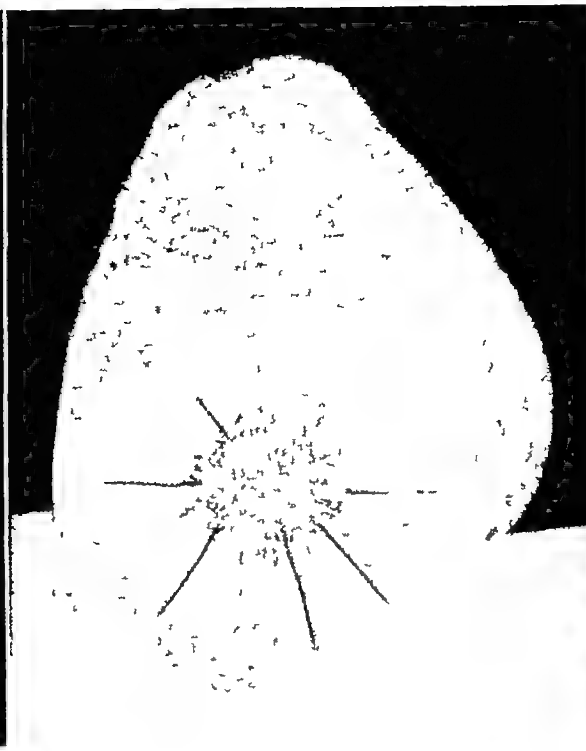

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Fig 89—Circular open amputation of the upper arm healed by scar, following skin traction, bandaging, and whirlpool therapy Final surgery requires only excision of the stellate scar and plastic closure of the wound (Walter Reed General Hospital Neg No 4518 2)

Fig 90—Circular open amputation of a below knee stump with a small, clean, terminal granulating area surrounded by circumferential cicatrix, following traction, bandaging, and whirlpool The infolded areas of skin, which radiate from the central defect like the spokes of a wheel, must be considered surgically as circulatory barriers similar to scars remaining after wound healing Final surgery includes excision of the granulating area and surrounding cicatrix and plastic repair to effect covering of the end of the stump (Walter Reed General Hospital Neg No 4535-1)

Fig 91—Circular open amputation of a below knee stump with a large clean terminal granulating area Note the softness and pliability of the skin typical of a well prepared stump Skin traction failed to pull the skin over the end of the stump because it was discontinued before maximum coverage was gained, cicatrix, which formed at the skin margin, blocked later attempts at traction (Walter Reed General Hospital Neg No 4599 2)

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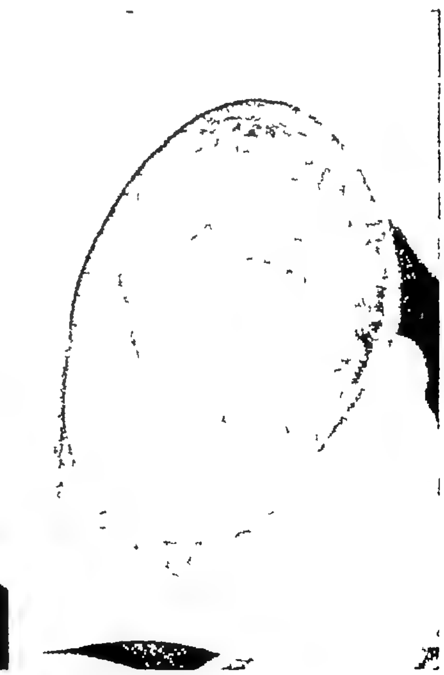

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Fig 92—Flap type of open amputation with large terminal granulating area Traction is always less effective in this type due to early fixation, by cicatrix, of the longitudinal upward extensions from the end of the stump Considerable skin which might be utilized during final surgery is also lost through the excision required to form the flaps Repair is effected by excision of granulating area, cicatrix, deep soft tissues and bone, followed by plastic closure of the skin (Walter Reed General Hospital Neg No 4273 1)

Fig 93—Open amputation of the upper thigh near the hip joint The granulating wound has been covered by a split thickness skin graft to eliminate surface infection and edema of the surrounding tissues prior to closure (A graft is admissible here, for traction is notoriously ineffective at this level) Final repair consists of removal of the graft and underlying protruding bone, and the shifting of large skin flaps (Walter Reed General Hospital Neg No 4556 1)

Fig 94—Well healed open amputation through the mid-tarsus following surgical debridement and cleansing of the open wound preparatory to Syme amputation (Walter Reed General Hospital Neg No 4513 2)

granulation tissue and skin lie proximal to the bone section, all posterior soft tissues are cut at the saw level and the granulating area is allowed to remain In either event, no attempt is made to free the posterior skin from binding scar The wound is dressed and traction is applied with five pounds of weight This is gradually built up to ten to fifteen pounds Traction is maintained until the maximum downward progression of the anterior skin is obtained This usually requires three to five weeks The wound is dressed as infrequently as circumstances will permit

FINAL REPAIR OF THE OPEN AMPUTATION STUMP

After the preliminary preparation of the open amputation stump is complete and the tissues are clean and healthy, final repair, or final closure, is undertaken in order to obtain a well-healed, well-shaped stump capable of withstanding the pressure and strain which will be placed upon it The type of repair depends largely upon what normal and healthy tissues are available (1) reamputation and final closure at a higher level may be indicated, (2) plastic repair of the stump may be necessary, or (3) revision may be called for Not infrequently, accessory wounds will be present upon the stump and will require special care

Reamputation is simply what its name implies, another amputation carried out at a higher level, and it follows exactly the technique described for final definitive amputation It is indicated whenever the initial amputation is well below the ideal site of election As a general rule, it may be carried out earlier than plastic repair and revision, since it deals only with normal tissue at a distance from the original operative wound

Plastic repair is the remodeling of the soft tissues to provide skin covering without any disturbance of the bone It is indicated in an area of election where there are sufficient soft tissues about the bone to afford suitable integument the skin must be normal in character and sufficient in quantity to cover the bone end, the bone, itself, must present a contour approximating the normal, and the muscles and other soft tissues should supply good lateral padding to the sides of the bone Since this procedure is essentially plastic in nature, each case is an individual problem and must be dealt with as such There are, however, certain general principles which should be adhered to The following technique is presented as an outline of these principles

(1) A tourniquet is used
(2) The skin incision is made through normal healthy skin containing a good layer of subcutaneous fat and is placed so that the distal edges of the flaps which are formed lie as close as possible to the thick heavy scar that bounds the terminal granulating wounds
(3) This scar and the granulating area are resected from the end of the stump by sharp dissection Care is taken not to contaminate the underlying tissues
(4) When these steps are complete, the instruments are discarded, and a clean operative field remains
(5) The skin is now undermined in the cleavage plane between the superficial and deep fascia for a distance of one to three inches depending on how much mobilization of the skin is necessary to allow it to cover the end of the bone
(6) The skin flaps are reflected upward, and all scar is removed by block dissection to a point where the tissues appear to be well vascularized

(7) Muscle is excised to a point where all large bulky, redundant muscle masses are eliminated, and the stump assumes its normal, gently tapering form Since the muscle is firmly bound to the sides and end of the bone by scar tissue, its retraction need not be feared, and the fascial flaps which are used in the elective final amputation to group the muscles about the end of the bone are not necessary

(8) The bone, itself, is not disturbed, or, if it is, its treatment is limited to slight rounding and beveling to meet the needs of the local situation

(9) Any vessels which are seen within the operative field are isolated and ligated This is usually not too great a problem, for the major vessels have usually been thrombosed following the primary amputation

(10) The nerves are isolated, drawn gently down, and sectioned to fall an inch or so above the bone end

(11) The tourniquet is removed and hemostasis completed

(12) The skin is drawn down over the end of the stump and trimmed for approximation under normal tension There is no general rule as to the position of the skin flaps, covering must be effected in any way possible It is usually desirable to place the suture line as nearly as possible in the position recommended for ideal amputation, for here the likelihood of future irritation through pressure or tension is least

(13) The wound is closed carefully with interrupted sutures, and a drain is instilled between the two sutures nearest the angle of the wound

(14) Dry gauze dressings are applied, followed by sheet wadding and elastic bandage compression The skin should never be fixed under more than normal tension, since a broad, painful scar or breakdown of the wound will usually result If this rule is followed, traction should never be necessary after final repair

Revision is the plastic repair of the soft tissues together with the excision of a moderate amount of bone, with the objective of creating a stump which is as nearly ideal as possible It is indicated when the original open amputation falls within the area of election and the soft tissues cannot be used to cover the end of the stump, either because of lack of adequate normal skin and muscle or because the bone is too long or is misshapen The technique of the surgical procedure is essentially the same as that for plastic repair, differing only in the fact that some bone is removed The terminal granulating area and scar are excised through good skin near the scar tissue border Cicatrix is thoroughly débrided from the end of the stump, and the skin is undermined between the superficial and deep fascia and reflected upward The osteotomy site selected is the level at which there will be adequate muscle to protect the sides of the bone and sufficient normal skin to close over its terminus The periosteum is incised circumferentially at this point, and the bone is divided, smoothed, and beveled The bone dust is washed from the field with normal saline The muscle is trimmed to form a smooth tapering contour The major vessels are isolated, sectioned, and ligated, and the nerves are identified, drawn down gently, and sectioned to fall above the bone end The tourniquet is removed, and hemostasis is completed As in plastic repair, no fascial flap is required Closure is effected by interrupted sutures after the skin flaps have been trimmed to ac-

;ical objective of final closure is to supply skin cover to the hand without impairment of the streng ı, to preserve all useful length, and to eliminate nonfunctional segments which impair the utili

precepts

imar skin mobilizes poorly because it is thick, tough, and bound down to the deeper structures by s In planning flaps of palmar skin an extremely liberal allowance in length must always be made

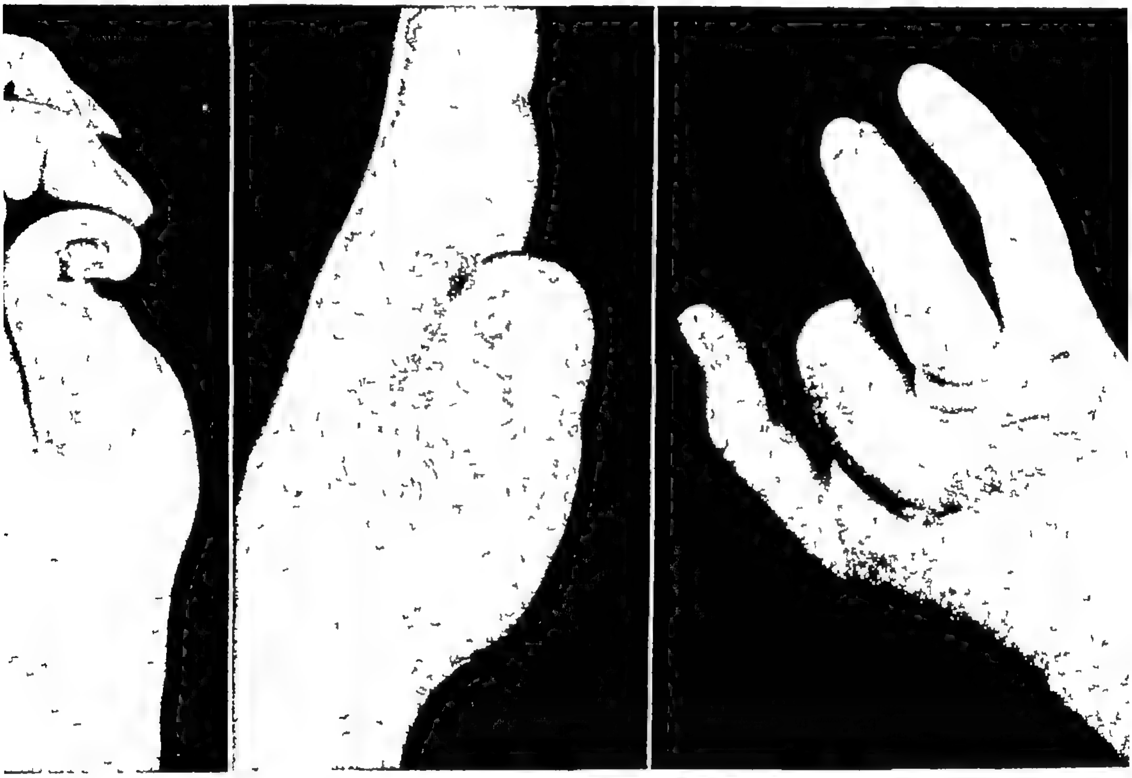
rsal skin is thin and elastic and mobilizes well

skin flap should always be delayed when the length of the flap is greater than twice the width of

:n cover lacking sensation should never be placed over pressure areas if skin with normal sei

the dorsum of the hand free split or full thickness grafts may be used On the palmar aspect larg more satisfactorily repaired by skin containing a cushion of subcutaneous fat

; closure of the skin defect is never effected in such a manner that contracture of a digit will res always preferred to a smooth, even suture line, and the flexion of a joint to facilitate closure is alway favor of the use of supplementary skin



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ompound fracture of the thumb at the level of the interphalangeal joint with loss of the head of t id base of the distal phalanx, partial loss of the base of the nail, and healing of the surrounding (Walter Reed General Hospital Neg No 4041-1)

ame case after final repair The palmar skin was brought back over the posterior aspect of the stun the distal phalanx was implanted into the freshened distal end of the proximal phalanx to minimize entire nail bed was thoroughly excised (Walter Reed General Hospital Neg No 4132 2)

'he skin from a useless amputation stump of the middle finger has been used to cover a skin defe irpal heads From a finger stump requiring reamputation, satisfactory skin may sometimes be salv s and tendons and their investing fascias The incision is made longitudinally down the stump on ct to be covered The skin is then dissected away from the underlying bone, tendon, and fascia wl ally at a level sufficiently high to allow free mobilization of the remaining skin (The tip of the fin iately around the nail bed often cannot be used because of the natural curvature) The skin is ther red area, from which cicatrix or healthy granulation tissue has been excised, and is sutured in positio atisfactory graft for covering small defects since it provides a normal skin with good subcutaneo ion (Walter Reed General Hospital Neg No 4413 2)

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Fig 98—A flap graft from the dorsum of the hand is transferred to the palmar aspect to supply padding and sensation in an area previously covered with cicatrix The defect left by the flap is covered by a split-thickness skin graft, which need not be as large as the flap because the adjacent normal tissues can usually be shifted (Walter Reed General Hospital Neg No 4439 1)

Fig 99—An abdominal flap is used to cover a denuded area in which no skin is available through local shifting This is not as desirable as a local flap because of the absence of sensation, but it does supply good skin cover and excellent padding (Walter Reed General Hospital Neg No 4852 2)

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Fig 100—Amputation of the thumb, index, and middle fingers with loss of the distal portion of the fourth metacarpal Poorly vascularized cicatrix covers the remnants of the thumb and a portion of the palm of the hand The granulating area at the base of the ring finger has a portion of sequestrated metacarpal head projecting from its centrum (Walter Reed General Hospital Neg No 4509 1)

Fig 101—Same case after preliminary preparation (Walter Reed General Hospital Neg No 4719 1)

Fig 102—Skin cover is provided The thumb portion of the tube was later fashioned to represent a rounded thenar eminence and the web space between thumb and index finger was smoothed to fill out the radial side of the hand This fulfilled the cosmetic requirement of a semblance of normalcy as viewed from the dorsum of the hand Function was limited to hook action with the ring and little fingers only (Walter Reed General Hospital Neg No 4817 3)

curate approximation under normal tension A drain is placed a stitch or two from the angle of the wound, and dry dressings are applied, followed by elastic bandaging over sheet wadding Traction is not used

Accessory wounds or scars upon the amputation stump are usually the result of auxiliary longitudinal incisions made for the purpose of débridement of an involved muscle group or for drainage of a sinus tract either at the time of the original procedure or subsequent to it, deep infolded creases, which appear most frequently on the posterior aspect of the thigh or leg or about the terminus of the stump, are usually the result of shrinkage of the tissues in combination with traction and compression bandaging Any such affections may give rise to complications for either of the following reasons (1) They may form circulatory barriers and impair the nutrition of the tissues of the stump, thus precluding sound wound healing and predisposing to eventual breakdown This is particularly true if they lie obliquely or transversely across the pathways of circulation, or if the scars and creases are large or adherent, or the cicatricial bases of the granulating wounds are deep, it is almost inevitable if they should be allowed to lie within a skin flap or across its base (2) They may be highly incompatible with the use of the artificial limb, for if they are bound down to underlying tissues they will be constantly traumatized by the piston action which occurs between stump and socket, and if they lie within a pressure area, especially over a bony prominence, they will be continuously subject to irritation, it follows without comment that a wound, healed by granulation and scar, could not be tolerated anywhere within the socket of the limb

When such wounds, scars, or creases are present at the time of final closure, the first consideration is to ensure by the fashioning of the flaps that they will not lie within a skin flap or proximally across its base, lest they deprive it of the nutrition which it must have to survive The second consideration is to excise them and replace them with linear scar with good subcutaneous padding If they lie in the proximal portion of the stump, this step can often be taken safely at the time of closure, if they fall near the amputation wound, any corrective surgery should be delayed until a later date if there is the slightest danger of its causing circulatory embarrassment in the skin flaps used for the integument of the stump end

In many instances the repair of accessory flaws upon the amputation stump can be accomplished by simply excising the infolded skin and granulations, removing the scar tissue base to a point where the circulation is abundant, smoothing the area so that no dead space is present, and undermining the skin at either side of the wound so that side-to-side approximation can be achieved Frequently, however, special care may be necessary When the area to be repaired overlies a subcutaneous bony surface, the tissues should be arranged so that the suture line will fall over adjacent soft tissues as much as possible, rather than over bone, for scars overlying bone usually become adherent and are subject to trauma during the piston action of the stump within the prosthesis When the suture line will fall over a joint, it should be interrupted in zigzag fashion so that there will be no likelihood of future impairment of joint motion through cicatricial contracture When two wounds, one on either side of the stump, must be closed, less skin covering is, of course, available, and considerable undermining and shifting of skin may be necessary, often it is the wiser course to close but one wound and delay closure of the second until the first has healed, thereby avoiding excessive tension and subsequent circulatory embarrassment and wound breakdown When infolded skin must be utilized to cover the wound, which is sometimes the case when a large amount of skin has been rolled inward toward the base of a crease or wound and its excision would not leave sufficient

FOREARM AMPUTATION

Final repair of open amputation of the forearm requires little variation from the standard technique Since the skin is soft, pliable, and easily mobilized, its rearrangement to cover the end of the stump presents little difficulty after excision of the scar or granulating bed and remodeling of the bone ends as required

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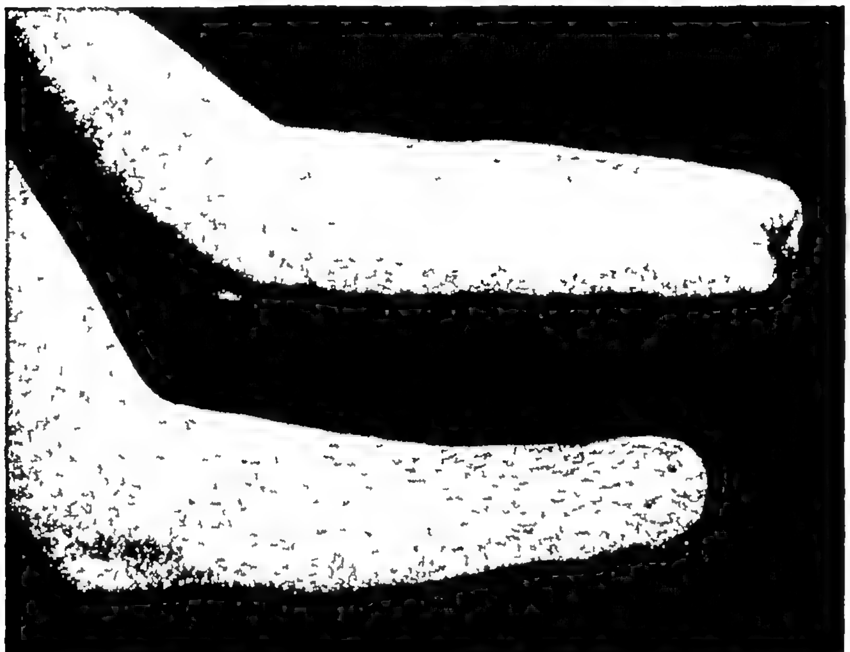

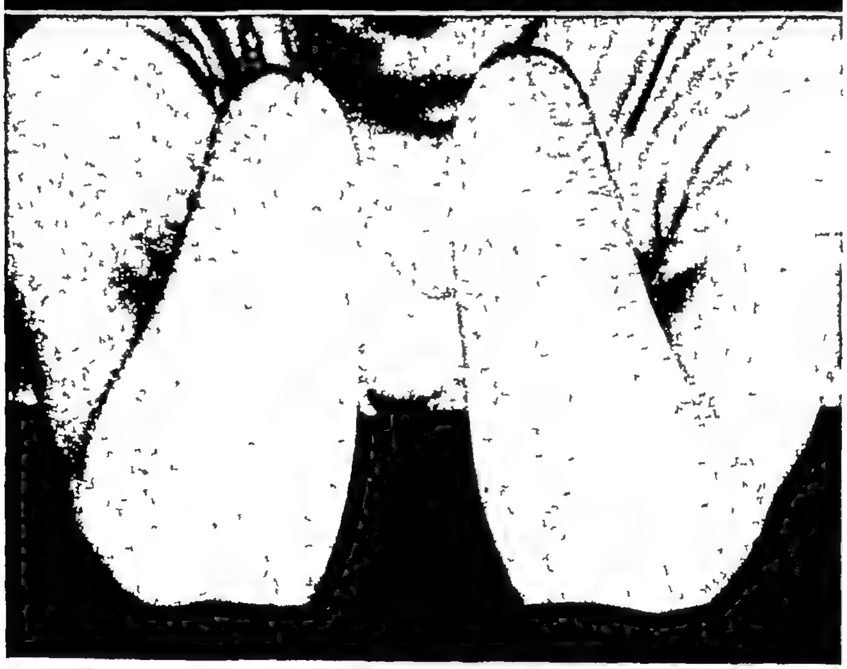

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Fig 103—Bilateral open amputation after preliminary preparation (Walter Reed General Hospital Neg No 4437-3)

Fig 104—Same case after plastic repair (Walter Reed General Hospital Neg No 4593 1)

value Here the diversity in the size, shape, and form of wounds within each limb segment taxes the ingenuity and imagination of the surgeon in planning and executing wound closure The truly plastic nature of amputation surgery is exemplified best in the closure of the atypical skin defects which are commonplace, especially when the bone length falls short of the ideal level for amputation The orthopaedic aspects lie in the handling of the deeper soft tissues and bone, and the surgical adaptation of the stump to the dynamics of the artificial limb without which no operative procedure may be deemed satisfactory regardless of appearance

In this section reamputation will not be considered since it follows the pattern described for formal amputation under a later section, but the plastic repair and revision required to effect closure will be viewed in the light of the anatomic peculiarities unique to each level

SHOULDER DISARTICULATION

The repair of open disarticulation of the shoulder presents one of the most formidable problems from the standpoint of supplying satisfactory skin cover The amputation wound is often extensive, multiple thoracic wounds are often present, and skin shifting must be done in a variety of patterns to meet the needs of each situation In women, care must be taken not to displace breast tissue lest an unsightly deformity result

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Figs 111 and 112—Variants of wound closure of open disarticulation In either instance large granulating areas were removed (Fig 111 Walter Reed General Hospital Neg No 4286 Fig 112 Walter Reed General Hospital Neg No 4417)

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Fig 113—Open disarticulation of the shoulder after preliminary preparation for final closure A large area of cicatrix and large thoracic scar are present (Walter Reed General Hospital Neg No 4362)

Fig 114—The same case after repair by the use of a large local skin flap and downward migration of the tissues overlying the top of the shoulder Although sensation in the flap was somewhat impaired due to the anterior placement of the base of the flap, this is permissible here since a prosthesis is not usually worn and the principal requirements are skin cover and adequate padding (Walter Reed General Hospital Neg No 4490 2)

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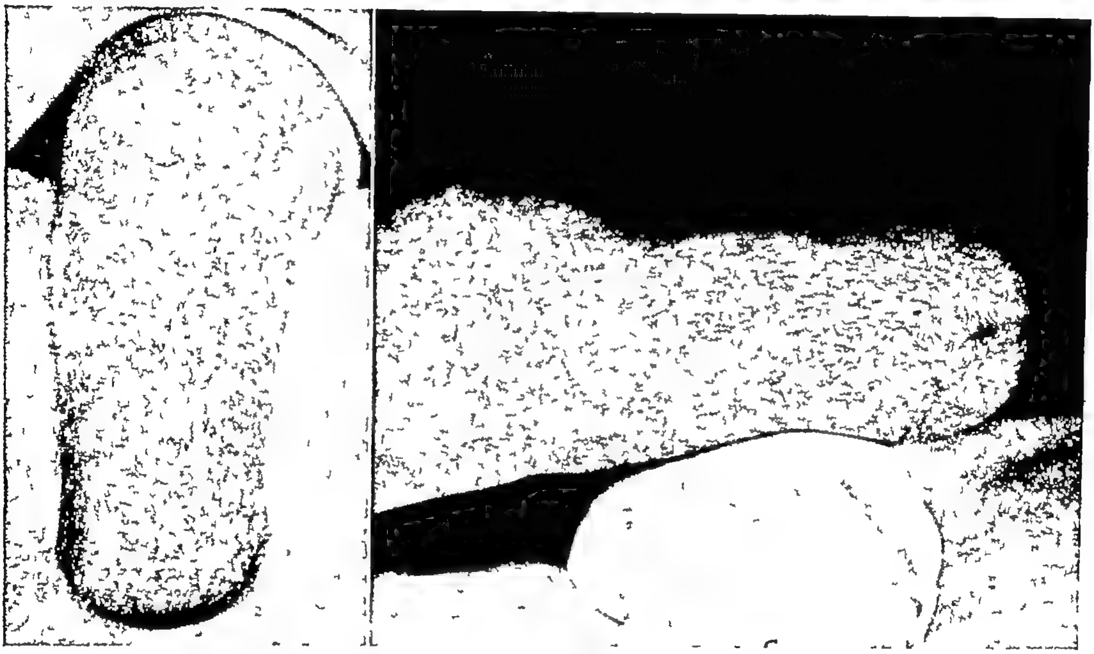
Fig 115—Open disarticulation of the shoulder with extensive involvement of the thoracic wall after closure by excision of the granulating area and surrounding scar, and the use of multiple skin flaps (Walter Reed General Hospital Neg No 4438 1)

Fig 116—Open disarticulation of the shoulder with extensive injury to the lateral thoracic wall, closed by excision of the cicatrix, shifting of multiple skin flaps and application of a split thickness graft to the remaining uncovered area The use of a free graft which possesses no sensation is permissible in the thorax where no pressure is borne (Walter Reed General Hospital Neg No 4474)

Fig 117—Appearance of the conventional circular open amputation below the knee following skin traction and preliminary preparation (Walter Reed General Hospital Neg No 4391 1)



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Figs 118 and 119—Same case, after plastic repair involving excision of the terminal granulating area and stellate scar, undermining of the anterior and posterior skin, and formation of flaps which were approximated under normal tension (Walter Reed General Hospital Neg No 4608 2,3)

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Fig 120—A very short below knee amputation after skin traction Traction is less effective here than at lower levels because of the difficulty in mobilizing the skin about the knee joint, especially in the popliteal region (Walter Reed General Hospital Neg No 4599 1)

Fig 121—Same case after plastic repair A bent knee prosthesis was used because of incomplete extension of the knee joint (Walter Reed General Hospital Neg No 4763 1)

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Fig 122—Open amputation healed by a deep, diagonal, infolded scar (Walter Reed General Hospital Neg No 4264 2)

Fig 123—Same case after plastic repair which was effected by complete excision of the infolded area, and side-to side approximation of the flaps thus formed In this instance, sufficient skin was available so that the bone did not have to be disturbed (Walter Reed General Hospital Neg No 4419 2)

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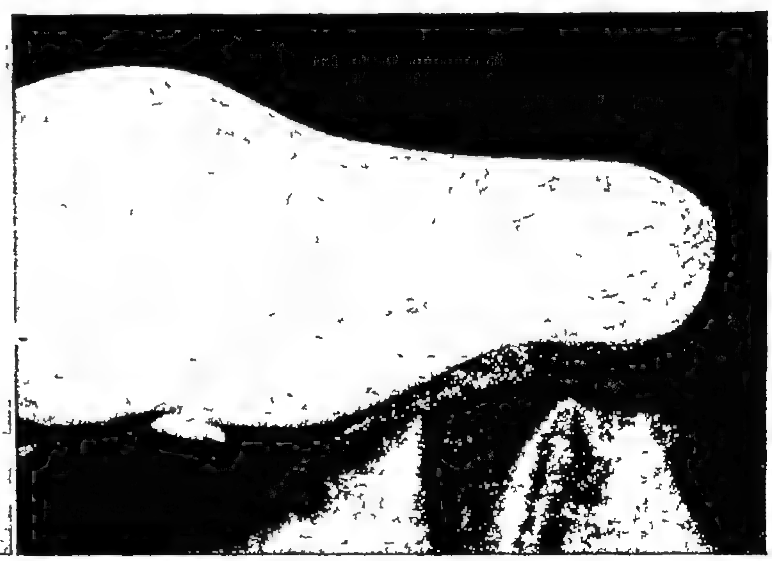

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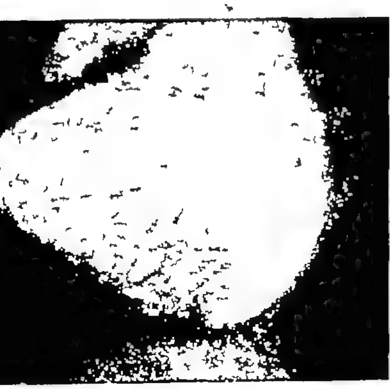
Fig 124—Open amputation healed by deep terminal and lateral scar (Walter Reed General Hospital Neg No 4357-1)

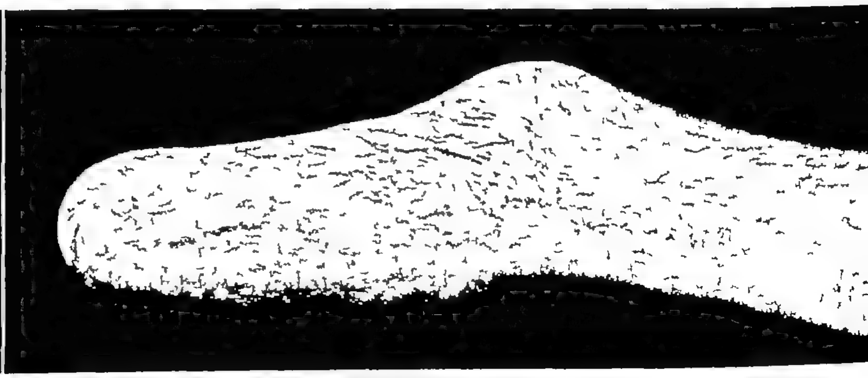
Fig 125—Same case after plastic repair, which involved excision of all infolding scar and plastic remodeling of the end of the stump (Walter Reed General Hospital Neg No 4639 2)

126 127

Figs 126 and 127—Flap type open amputation before completion of preliminary preparation (Walter Reed General Hospital Neg No 4272 1,3)

Fig 128—Same case after revision Observe the minimal loss of bone length and smoothly contoured stump (Walter Reed General Hospital Neg No 4789 2)





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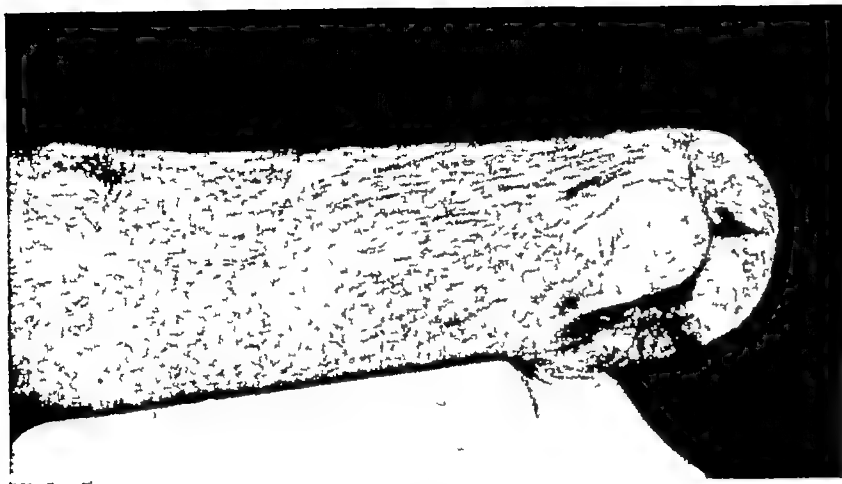
Figs 129 and 130—Postoperative photographs of a revised open amputation with extensive lateral wound extending to the mid thigh (Walter Reed General Hospital Neg No 4788 1,2)



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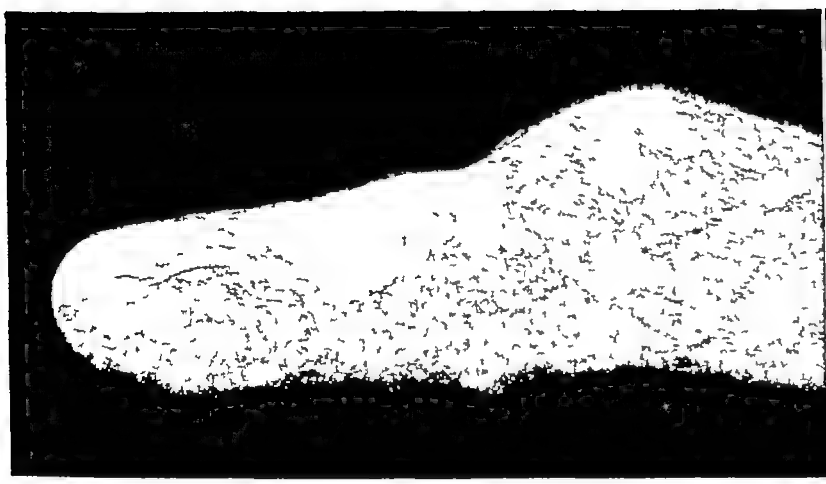

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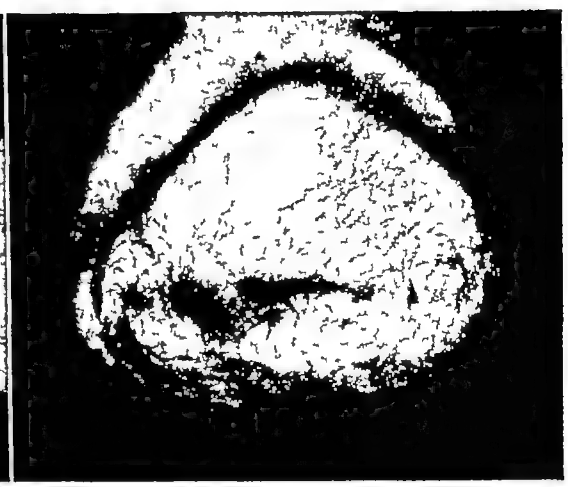

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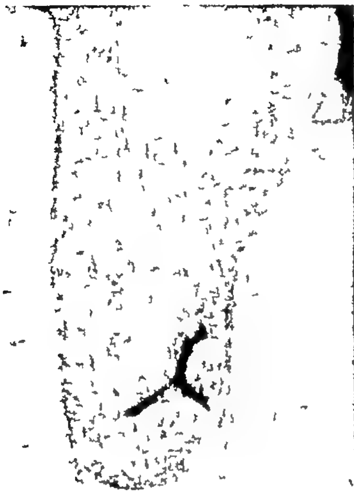
Figs 131-134.—Pre- and postoperative views of a long below-knee stump subjected to reamputation by the Carnes technique. Note the very short terminal scar, lying just posterior to the tibia, and the smoothly-contoured stump. (Walter Reed General Hospital Neg. No. 4407-2,3 and 4696-1,3.)

FLAP GRAFTS FROM THE AMPUTATION STUMP

The amputation stump may be used as the donor site of flap grafts for placement elsewhere on the body, provided that such surgery will not impair the future utility of the stump There are two circumstances under which such a procedure is feasible (1) When a large mass of healthy redundant skin is present below the bone and would not be utilized in repair of the stump itself, and (2) when the stump is excessively long so that reamputation at a proximal site of election is required In the latter instance the skin on the distal end of the stump would normally be discarded in reamputation



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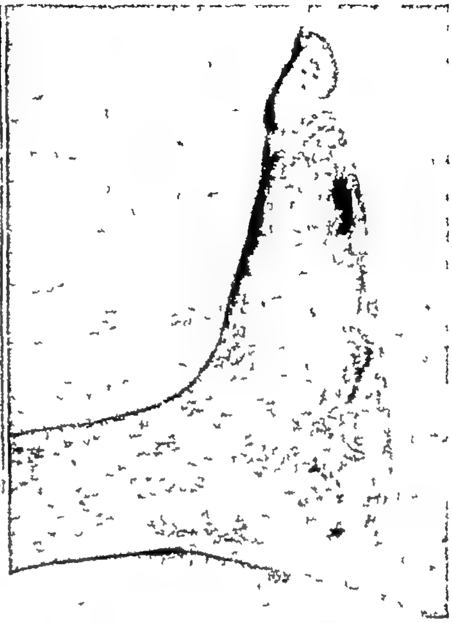

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Figs 135 138—Flap graft from a right below-knee stump to left foot

Fig 135—The stump The prominent bone end is visible anteriorly several inches above the terminus of the skin flap (Walter Reed General Hospital Neg No 4305-2)

Fig 136—The defect on the plantar and medial aspects of the left foot (Walter Reed General Hospital Neg No 4305-1)

Fig 137—The skin flap in position A cast was used to prevent movement during healing The bandage is used to give an idea of the eventual contouring of the stump (Walter Reed General Hospital Neg No 4393 2)

Fig 138—The completed graft (Walter Reed General Hospital Neg No 4632-3)

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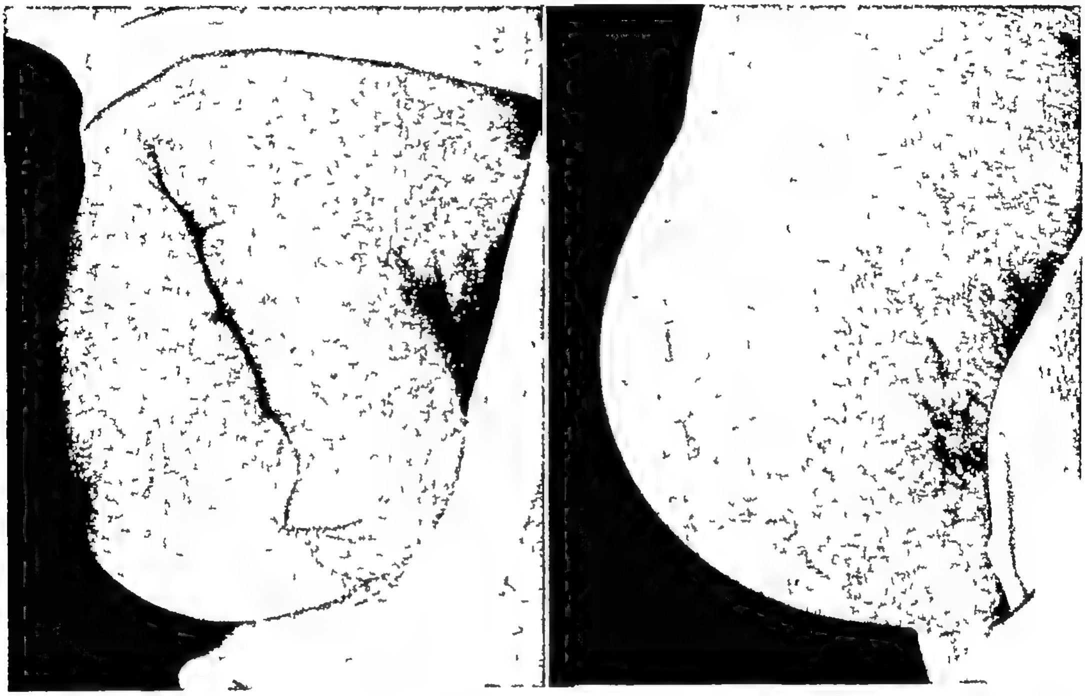
Figs 139 and 140—Flap graft from a right below-knee stump to left calf

Fig 139—Skin from the long below knee stump of the right leg was transplanted to the posterior calf of the left A split-thickness graft had previously been used to cover the defective area (seen nearest the reader) A portion of this graft was lifted to allow placement of the flap over the underlying tissues, and that lifted portion was then used to cover the exposed surface of the flap and the denuded area on the stump from which the flap was taken (Walter Reed General Hospital Neg No 4635-1)

Fig 140—Left leg showing the completed graft (Walter Reed General Hospital Neg No 4918 3)

repair of the above knee open amputation, the skin and soft tissues utilized are readily workable from
As to the skin, it is separated from the underlying muscles by a definite fascial cleavage plane, its
ood supply is excellent, and it is readily mobilized when formed in large flaps, as to the muscles, they
m excellent lateral padding for the bone at this level In addition to the satisfactory quality of t
the fact that a single bone is present above the knee simplifies the shaping of the stump at the tin
the simple, circular open amputation has been performed, the plastic repair or revision required pre
the general principles are followed The terminal scar or granulating area is simply excised, the bone
ed as necessary, muscle grouping about the bone end is ensured, and the skin, after necessary unde
out, is brought downward over the bone end under normal tension Skin flaps are trimmed to fit in th
utation wherever possible When necessity has dictated an open amputation pattern which presents la
, however, the routine repair may have to be varied considerably Fortunately the structures of th
extensive plastic reconstruction, and such atypical situations can be met satisfactorily, as the foll
w



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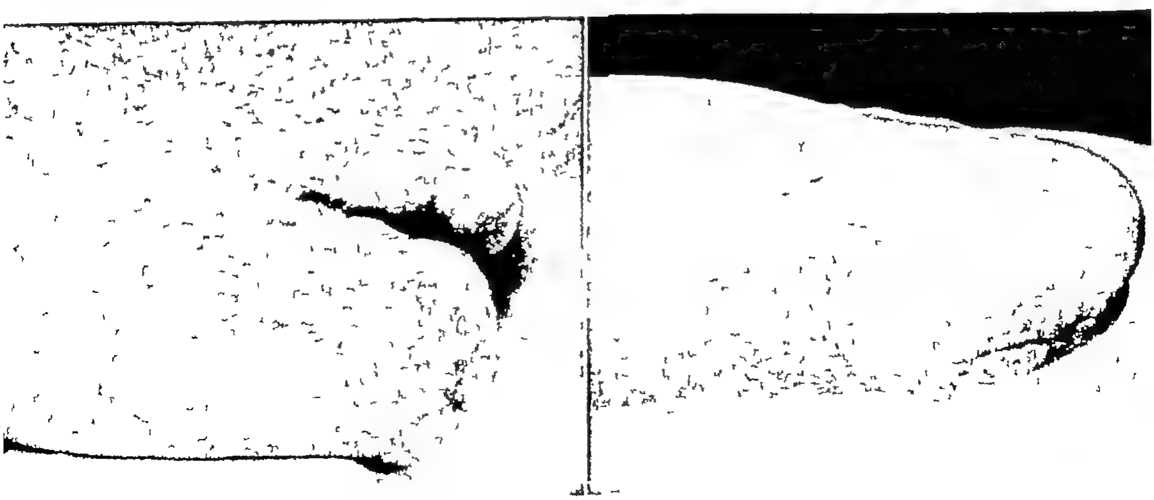
141 and 142—Amputation through the upper one third of the thigh healed by deeply invaginated scar
41—Preoperative photograph (Walter Reed General Hospital Neg No 4708-4)
42—Postoperative photograph (Walter Reed General Hospital Neg No 4846 1)



143 144

143 and 144—Amputation through the junction of the middle and lower thirds of the thigh with seco
rainage
143—Preoperative condition showing the deeply invaginated scar and the normal, healthy surrounding sk
eneral Hospital Neg No 4264 1)
44—Same case four weeks postoperative (Walter Reed General Hospital Neg No 4419 1)

146

Figs 145 and 146—Amputation through the middle third of the thigh with a large terminal and anterior granulating area

Fig 145—Preoperative status of the wound before preliminary preparation of the stump is complete (Walter Reed General Hospital Neg No 4327 3)

Fig 146—Postoperative condition of the stump three and one half weeks following surgery (Walter Reed General Hospital Neg No 4502 3)

147

148

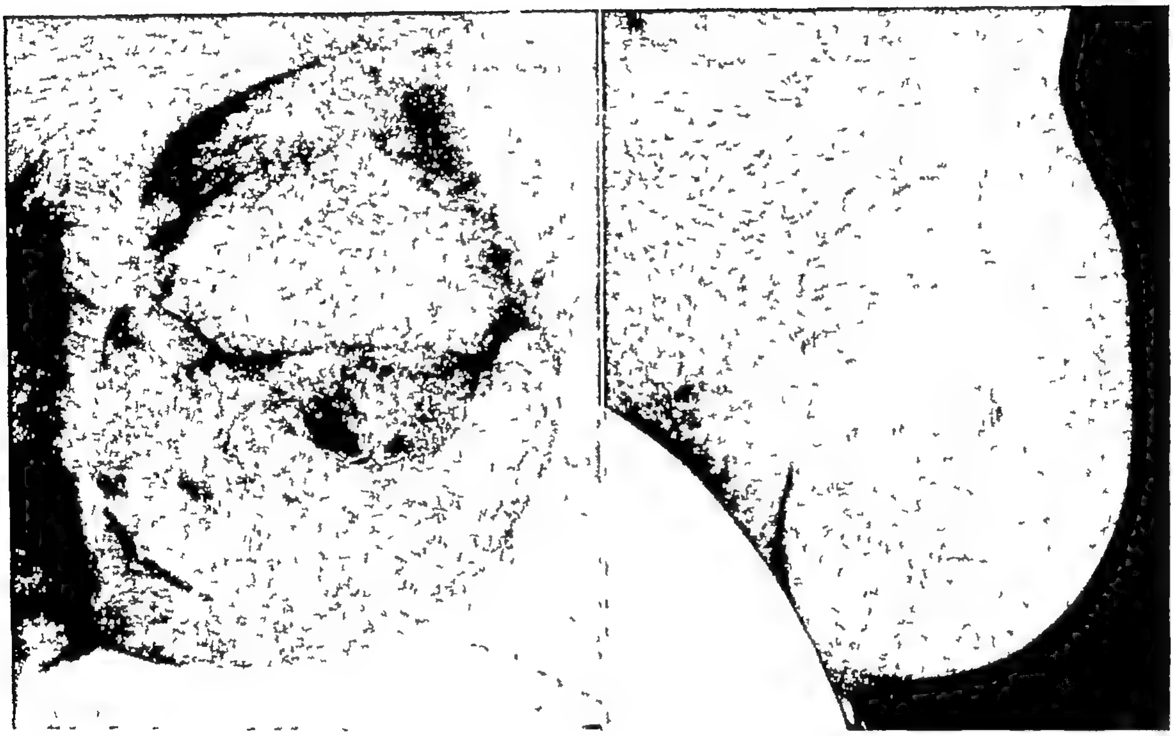
149

Fig 147—Amputation of the middle third of the thigh with medial and lateral flaps to effect closure (Walter Reed General Hospital Neg No 4764 4)

Figs 148 and 149—Front and terminal views of mid thigh amputation repaired through the use of multiple skin fla (Walter Reed General Hospital Neg No 4839 2,4)

OPEN AMPUTATIONS ABOUT THE HIP

In the repair of open amputation about the hip, skin is seldom available to consummate wound closure in a manner similar to that in formal amputation. It is frequently necessary to mobilize local skin flaps for a considerable distance in order to obliterate the defects remaining following the excision of scarred or granulating areas. Here it must be borne in mind that the skin covering the gluteal region is thick and difficult to mobilize because of the strong fibrous bands binding the subcutaneous tissues to the gluteal muscle fascia, and, therefore, extremely liberal allowance for length must be made when they are planned, undermining of the skin is carried out in the interval between the subcutaneous fat and the gluteal fascia in order that the circulation of the skin will not be disturbed. On the anterior surface of the stump the skin is thin and elastic to permit free flexion of the thigh, such skin mobilizes poorly in most instances, and it is usually better to undermine the skin of the lower abdomen and shift it downward, than to try to stretch the thin skin of the groin alone over a defect for closure. Frequently the open amputation defect will extend to the external genitalia. Here the normal relationship of the tissues should be maintained as nearly as possible for the physical and psychological comfort of the patient, even though this may require extensive plastic readjustment. In the male, particular care is always taken to preserve the spermatic cord whenever it is possible to do so. When the tissues about the anus are involved, it will frequently be necessary to repair the external sphincter in addition to eliminating granulation tissue and scar. The region over the ischial tuberosity, the principal weight bearing point, should always be provided with normal skin covering which has normal sensation and is free from scar. Although it is preferable to leave a portion of the upper femur within the stump for prosthetic reasons, it is frequently necessary to remove a part or all of this bone to effect closure of an anterior granulating area. Should this be necessary, it should be carried out extraperiosteally to avoid the formation of undesirable new bone which so frequently follows subperiosteal excision. Regardless of the type of closure effected it is desirable to place the suture lines as far from the anus as possible in order to avoid the possibility of fecal contamination. I have made it a practice to use drugs, preoperatively, which tend to reduce the bacterial flora of the intestinal tract.



150 151

Figs 150 and 151—Open disarticulation of the hip with extensive wounds about the groin

Fig 150—Preoperative status Note the size of the granulating area and the scar tissue of the anterior hip region (Walter Reed General Hospital Neg No 4293 1)

Fig 151—Postoperative condition (Walter Reed General Hospital Neg No 4706 2)

Figs 152 154 —Open amputation through the l
of the femoral neck

Fig 152 —Preoperative condition, showing gra
lating area overlying projecting bone end, and
rounding cicatrix (Walter Reed General Hosp
Neg No 4447 1)

Fig 153 —Condition following resection of
femoral neck and the terminal granulating area
split thickness skin graft has been applied (Wa
Reed General Hospital Neg No 4630 1)

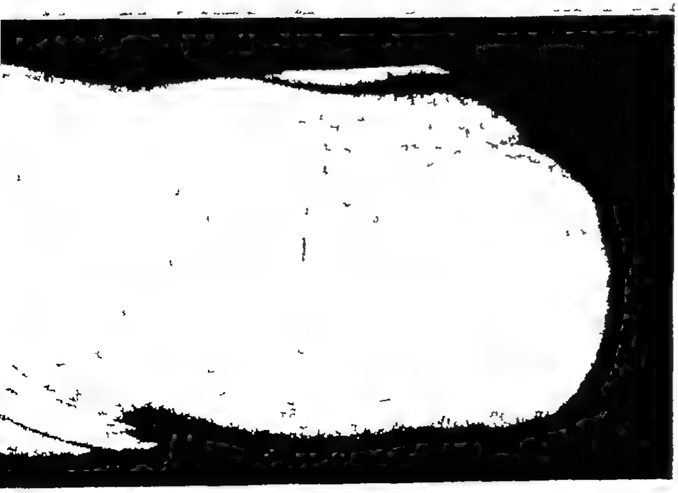


Fig 154 —Further closure of the defect follow
excision of the scar tissue border and a portion
the skin graft Adjacent skin flaps were mobili
to their fullest extent to effect their shifting T
remaining portion of free skin graft is satisfacto
since it is not in a pressure area The "dog ea
at the lateral aspect of the suture line was la
removed (Walter Reed General Hospital Neg N
4871 1)

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Figs 155 and 156—Front and side view of an open amputation defect repaired through use of a sliding flap and auxiliary split-thickness skin graft Although cosmetically excellent, such sliding grafts are likely to lose sensation since the incoming sensory nerves are sectioned It would have been preferable to have the base of the flap lateral rather than medial, but this was not practical in this instance (Bushnell General Hospital Neg No 8779)

VI. CLOSED AMPUTATIONS

AMPUTATIONS OF THE UPPER EXTREMITY

AMPUTATIONS THROUGH THE FINGERS AND HAND

General Considerations

The objective of every amputation of the fingers or hand is to obtain an ideal stump from both a functional and a cosmetic viewpoint

The hand is an intricate mechanism, each element of which contributes to one or more of its three basic functions—grasp, pinch, and hook The thumb is of great importance in grasp because of its polar position, and it is absolutely vital in pinch With regard to the fingers themselves, the index and middle fingers are the most important in all three functions because of their proximity to the thumb and because they are the strongest and most stable, due to their relative fixation at the carpometacarpal articulations The ring and little fingers, on the other hand, have a wider range of motion at their articulations and, thus, because of their position, provide mobility in the metacarpal arch and aid in the combined dexterity of all the fingers This is readily illustrated in the action of picking up several small objects at a time such as nuts or beads Like the thumb, the little finger is an important factor in grasp, for it increases the span The chief value of the palm lies in its breadth For example, in the use of a hammer, the fingers force the handle into the fold of the palm, resulting in a firm, unwavering grip Consequently, any decrease in breadth of the palm will proportionately lessen the stability of the grasp

Fingernails are an aid in picking up such things as coins or pins, as well as acting as protection for the back of the finger They should be saved whenever practical

The skin is the most vital single tissue in the amputation stump It provides tactile sensation and allows mobility There must be provision for a skin covering which has good sensation, and which is adequate enough to avoid tension The fingers and thumb must withstand constant trauma, and, therefore, the tough palmar skin is used to cover the bone end in preference to the tender dorsal skin A long palmar and a short dorsal flap are used These should be cut long enough so that they will cover the end of the stump freely If they are taut, there will frequently be local skin slough, wide, tender, and painful scars, and limitation of motion because of the subsequent check action of the tense skin covering Accurate approximation of the skin must be accomplished, even though this may mean the sacrifice of bone length in cases where special plastic methods are not indicated In acute trauma, finger length may frequently be saved by immediately covering skin defects with grafts, failure to provide skin will lead to infection and cicatrix, and these may often impair function through limitation of motion

The tendons provide mobility for all of the functions of the hand, an the treatment of them is a simple but important element in finger amputation It must be remembered that each phalanx has its individual motor supply When the fingers are in the neutral anatomical position of 180 degrees, th distal phalanx is extended by the intrinsic muscles and flexed by the flexo profundus, the middle phalanx is extended by the intrinsic muscles and flexed by the flexor sublimis, the proximal phalanx is extended by the common extensor muscles and flexed by the lumbricales When the fingers lie in flexion beyond the neutral 180 degrees, though the flexor muscles involved in motion of the distal and middle phalanges remain the same, the intrinsic muscles, which otherwise extend them alone, are now reinforced by small slips from the common extensor Since each unit of the digit has an individual motor supply, it is entirely unnecessary to suture those tendons which function beyond the site of amputation Though such a procedure is often done, with the intent of adding power or ensuring motion to the proximal joints, it accomplishes nothing, and may be definitely detrimental to function, since it is frequently the basis of flexion or extension contractures The effect of these contractures on the normal function of the hand may readily be demonstrated by the following simple maneuver An extension contracture may be simulated by forcibly holding the ring finger in hyperextension and trying to make a fist It will be noted immediately that the fingers cannot be fully closed into the palm Next, one may hold the ring finger in acute flexion and attempt to open the hand It will be seen that normal extension of the fingers will be greatly hampered In dealing with tendons, the extensors are simply cut and allowed to retract The flexors, however, must be sectioned in such a manner that the severed end will retract above the level of the transverse carpal ligament at the wrist, so that it will not form adhesions to adjacent tendons and soft tissues This can usually be done by applying strong traction on the tendon, with the wrist in the flexed position when the section is made To ascertain that this has been accomplished, the portion of the tendon which has been removed is placed with one end at the incision and the other end over the wrist In some instances it will be necessary to make a separate transverse incision at the level of the wrist for the removal of the tendon

It is apparent from the preceding discussion of the various structures in the hand, that each contributes in some degree to one or more of the vital functions Therefore, the general rules for amputation in this part are (1) to maintain all structures insofar as is possible, (2) to retain the most functional combination of elements when some loss is inevitable, and (3) to preserve sensation, muscle strength, and mobility A fourth general rule is to maintain maximum length, but this demands further comment in that there are two factors other than lack of available tissue which justify its modification—the occupation of the amputee, and the relative importance of cosmesis in the individual case Occasionally, for occupational reasons, function may be improved by sacrificing some length to avoid awkwardness and inconvenience For example, to the man who does physical labor, a short stump in the index finger or little finger is no detriment, whereas its excision would narrow the palm and lessen the stability of grasp so important to him, but to the man who does fine work with his hands these stumps would protrude and prove a hindrance Thus, the occupational factor often becomes a functional one as well The second consideration, cosmesis takes precedence over function in many cases, such as in women and in those much before the public eye Here stability and length are of secondary importance and a pleasing contour and an appearance of normalcy are the aim toward

this end amputation through a metacarpal, or finger disarticulation may be deemed feasible. Although disarticulation of the fingers has often been considered unfavorable, it is perfectly satisfactory if the articular cartilage of the joint is excised so as to eliminate bulk, and enough bone is removed so that the stump will not protrude beyond its fellows.

Indications

The general indications for amputation in the hands are the same as those for the other extremities, but the structure of this unit and the discriminatory functions demanded of it make the damage from trauma, infection, and disease more disabling. The specific indications for amputation through this part are:

1. **In the acute traumatic hand.**

a. *When a severe compound fracture involves a joint, and such irreparable damage is incurred that the joint when healed will be completely or partially ankylosed.* Such a fracture is difficult to control; the surrounding soft tissues are macerated, infection is present or imminent, and it is self-evident that the finger or a portion of the hand so injured will serve no useful function and should be sacrificed.

b. When two or more structures are involved, and the surgeon is able to predict with a fair degree of certainty that the digit or portion of the hand will be useless, for example: loss of skin together with injury of the underlying tendon, loss of skin associated with a fracture, which in itself would not indicate amputation, severance of tendons in addition to severance of the principal digital nerves, etc.

In contradistinction, amputation is not indicated in the loss of only one structure, for severance of a tendon may be repaired, division or partial loss of a nerve may be remedied by suture, fractures may be reduced, and loss of skin replaced. With adequate care, these conditions may be treated with the anticipation of partial or complete restoration of function.

2. **In the infected hand.**

a. Uncontrolled infection whether of hematogenous or external origin.

b. Controlled infection in which the end result will be loss of function. The purpose of amputation in such cases is to shorten the convalescent period and remove a useless part.

3. **In tumors.**

a. Malignant.

b. *Benign, in which the removal of the growth would destroy function.*

4. **In cases of deformity.**

This includes all deformities in which function of the hand would be improved by removal of the deformed part. For example, stiff, straight, useless fingers not closing into the palm of the hand, and marked flexion contractures without reconstructive possibilities. These conditions are most commonly the result of posttraumatic or postinfectious ankylosis or contracture, and pernicious surgical and traumatic scars.

Finger-Tip Amputations

Finger-tip amputations are a frequent sequel of injury. The importance of securing an excellent result, particularly in skilled manual laborers, cannot be stressed too strongly. An ideal result will have adequate well-padded skin,

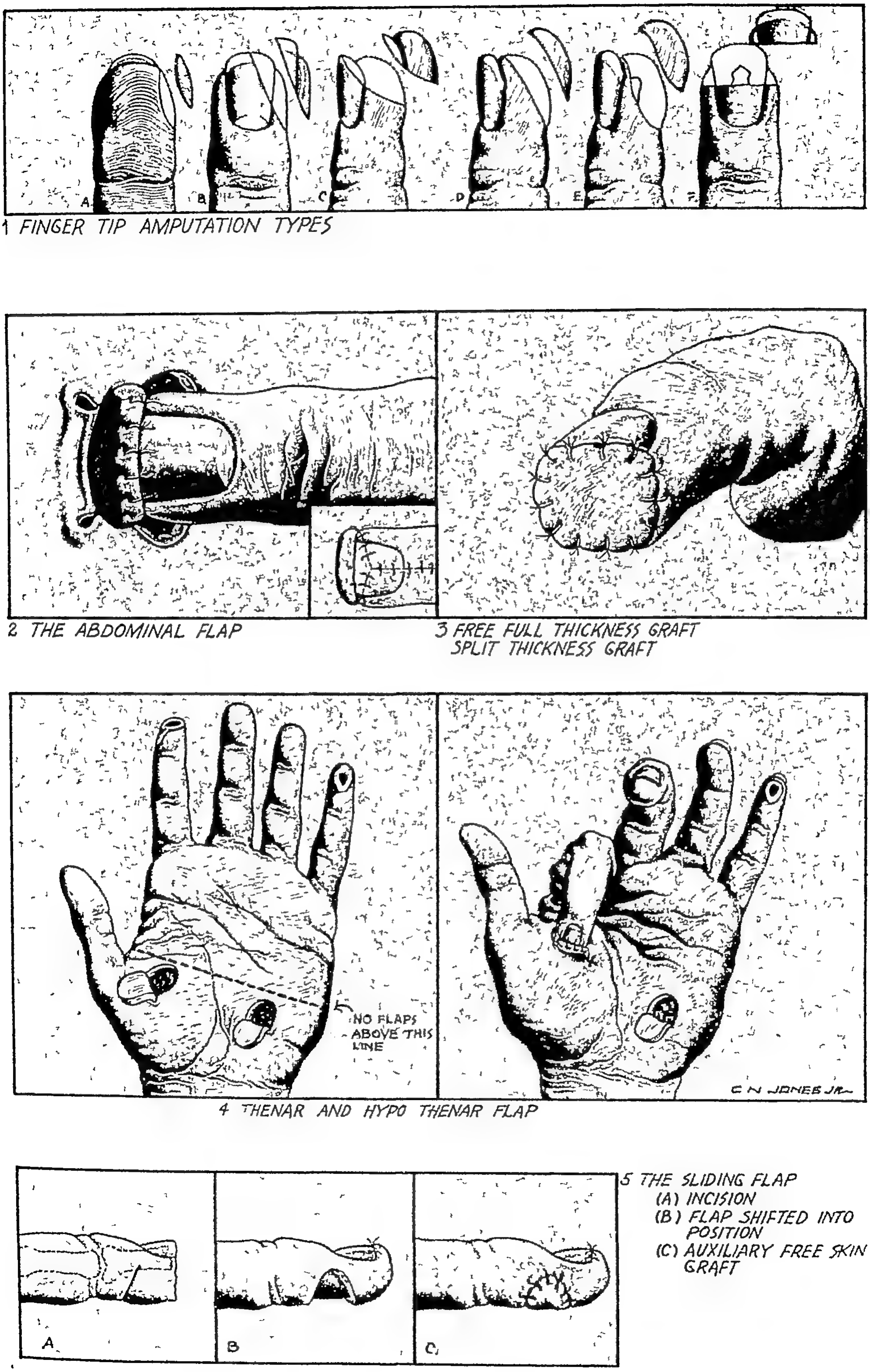

Fig 157 —Fingertip amputation

relative freedom from scar, and good cosmetic appearance. Since direct pressure is seldom borne upon the tips of the fingers, normal sensation although desirable is not imperative and therefore skin grafts are permissible. The importance of padding by subcutaneous tissue should be stressed, for its absence will result in adhesions which are painful at the extremes of motion. Healing by granulation alone results in dense scar tissue which is invariably tender and adherent and has a tendency to break down easily with minimal trauma, and usually results in reamputation or further plastic procedure. Open amputation is justified only in cases where infection exists, where bone or soft tissue involvement is extensive, or in instances where the safe period for primary closure has passed.

Finger-tip amputations may be of several types. These differ only in that the location of the wound varies in position. Skin alone may be involved, or skin in combination with fingernail and bone. The problem in each case is essentially the same: namely, preparation of a clean wound base and adequate skin replacement.

Immediate Treatment of Finger-Tip Amputations

Free Full-Thickness Graft

The free full-thickness graft is the method of choice in most finger-tip amputations. It preserves the length of the finger and provides an excellent soft tissue covering. Scar and sensitivity are minimal. The contour is cosmetically superior to that achieved by any other type of skin graft. The period of disability is reduced to a minimum, and the patient can usually return to work at an early date.

Technique

1. Surgical preparation of the finger and donor site.
2. Débridement of the wound, including the bone which is trimmed to the level of the surface of the wound. All loose skin tabs and necrotic material are removed.
3. The donor area may be from any skin surface, but preferably is from an area where subcutaneous fat is minimal and the skin is normally pliable. The flexor surface of the forearm is the most convenient area, but should not be used in women for cosmetic reasons. Other common donor sites are the groin and the lateral aspect of the thorax. A pattern of the granulating area should be taken by those inexperienced in the technique, allowing for 30 to 50 per cent shrinkage of the graft. The more experienced will judge the size of the graft with ease. No special instruments are needed. The graft is outlined and severed from its bed. No subcutaneous fat should remain on the undersurface. It is preserved in a sponge moistened with saline until it is fixed to the wound. The skin about the donor site is undermined and brought together, and closure is effected by several fine interrupted sutures.
4. The skin graft is transferred to the denuded finger tip and fixed with interrupted sutures. Care must be taken that complete hemostasis is present. Best results are secured when slight tension is placed on the graft. No excess of skin graft is permitted, all overlapping edges being trimmed to fit the wound.
5. The postoperative dressing should be a firm, snug pressure dressing, well maintained by a finger splint to effect immobilization and to protect the finger.
6. Postoperative care. The general principles of skin grafting are followed. The first dressing is done on the sixth to eighth day, and successive dressings not oftener than every two to three days thereafter. Moderate pressure is

exerted evenly over the graft. Gauze impregnated with petrolatum jelly, scarlet red, or Xeroform is used to keep the graft from sticking to the dressing. Pressure should be maintained over the graft for two weeks. Protective dressings should be used for an additional two weeks. After this period, warm water soaks and exposure to air may be permitted.

Split-Thickness Graft.

Another type of skin graft for finger-tip amputation is the free split-thickness graft. This is applied in the same manner as the full-thickness graft. However, the resulting pad over the finger is thinner, more adherent, and has little tendency to develop subcutaneous fat. Return of sensation does not take place in the split-thickness graft as it usually does in the free full-thickness graft.

Flap Graft

The flap graft is an excellent method of covering the finger tip. However, the operation is technically slower and more difficult than the free full-thickness graft, and the immobilization of the hand to the donor site limits the patient's activities.

A flap of skin including the subcutaneous tissue is turned up from the donor site in the direction necessary to cover the defect. A flap reflected for use on the cut terminal end of the finger tip would naturally be on a different plane from that for use on the side of the finger or the nail bed. The flap is sewn in position with fine interrupted sutures, and the bed of the graft undermined and closed by approximating the skin edges.

The most frequently used donor areas are the abdomen and the lower ribs of the opposite side of the body. The fact that the hand must be maintained in an unnatural position makes the procedure somewhat precarious, for, unless great care is taken by the patient, he may inadvertently pull the hand away from the donor site, thus severing the finger tip from its graft.

Flap grafts utilizing the skin of the thenar eminence and palm of the hand may also be used. These grafts afford an excellent covering for the finger tip, and have the advantage of not immobilizing the hand to the trunk. On the other hand, a scar is placed on the palm, and there is always the possibility of an undesirable cicatrix when imperfect healing takes place. To minimize the effect of such a scar, the proponents of this method stress the fact that the flaps should not be taken distal to the thenar and hypothenar eminences. The position of the flap is dictated again by the position of the finger-tip defect. Although I have seen excellent results from this method, I am hesitant to place an additional scar on the hand while other methods exist.

The Sliding Flap Graft

The sliding flap graft described by Woughter is an excellent method for providing cover in reconstruction of finger-tip amputations, for it affords skin containing good padding and sensation. It has as its principle the maintenance of tactile sensation by placing a skin flap containing the whorl, the most sensitive portion of the finger, over the denuded area. This is accomplished by shifting a flap of skin distally in much the same way in which the visor of the helmet in a coat of armor is raised.

TECHNIQUE

After débridement in a fresh injury or excision of the scar in an old injury, an incision is made, starting at the mid-lateral aspect of the finger, slightly proximal to the whorl, and extending across the palmar surface to a similar

point on the opposite side of the finger The level of the incision is determined by the desired width of the flap, which, in turn, is dependent upon the amount of the exposed finger tip to be covered Next, the skin is undermined and the distal end of the exposed bone is cut back sufficiently to allow the skin to fall over it without tension The flap is fixed by a single suture through the nail, and a compression dressing is applied

The principle of the sliding flap graft may be used also at levels above the finger tip when it is desirable to supply a tactile pad At these levels, the whorl, of course, is not available, and it is preferable to use a posterior rather than an anterior flap in order to avoid further scarring on the palmar surface

Reamputation

An alternative to the above methods is simply to reamputate the finger to such a level that the skin may be easily closed over the bone end This, of course, is the simplest method to carry out, but it is attended by the greatest loss of valuable length

Delayed Treatment of Finger-Tip Amputations

When no definitive treatment has been carried out during the first twelve hours after injury, it is probably better to leave the wound open and apply wet compresses, with a view to skin graft or revision as soon as the granulation tissue appears healthy Firm, pink granulations, clean and free from necrotic material, are the objective prior to the definitive treatment When the tissues take on this appearance, and the surrounding soft tissues are pliable and free from edema and infection, skin graft or wound excision with final closure may be carried out without further delay

Amputation Through the Finger

In amputation through the finger it should be remembered that the strength of the hand is lessened with the loss of each digit and each fraction of length within a digit, and that severance should be carried out at the most distal level compatible with sound integument, the only exception being in those cases where a protruding stump is contraindicated by the cosmetic demand, or by its awkwardness relative to the occupation of the patient

1 **The skin flaps** should be planned so as to result in long palmar and short dorsal flaps, the length being in a ratio of 2 1 The incision for the palmar flap starts on either the medial or lateral aspect of the finger at the midline of the bone (A view of the cross section will reveal this to be slightly posterior to the midline of the finger in the side view) It curves first distally and anteriorly and then proximally to end at a similar point on the opposite side of the finger The flap is tongue-shaped rather than semicircular The dorsal flap is cut in a similar manner, in accordance with the length ratio noted above Care is taken to make the angle at the sides of the wound wide enough to avoid the creation of projecting "dog ears" of skin If these occur, they are eliminated by a simple V-plastic incision

2 **The bone** is sectioned at a level which allows easiest approximation of the skin In sectioning the bone in this area, it should be remembered that the use of a bone-biting instrument will frequently cause a bursting type of fracture of the phalanx because of its nutcracker action This often results in excessive callus or arthritic changes if the fracture extends into a joint It is preferable, therefore to section the bone with a saw or to make several bites with the rongeur, taking only a small portion of the circumference at a time

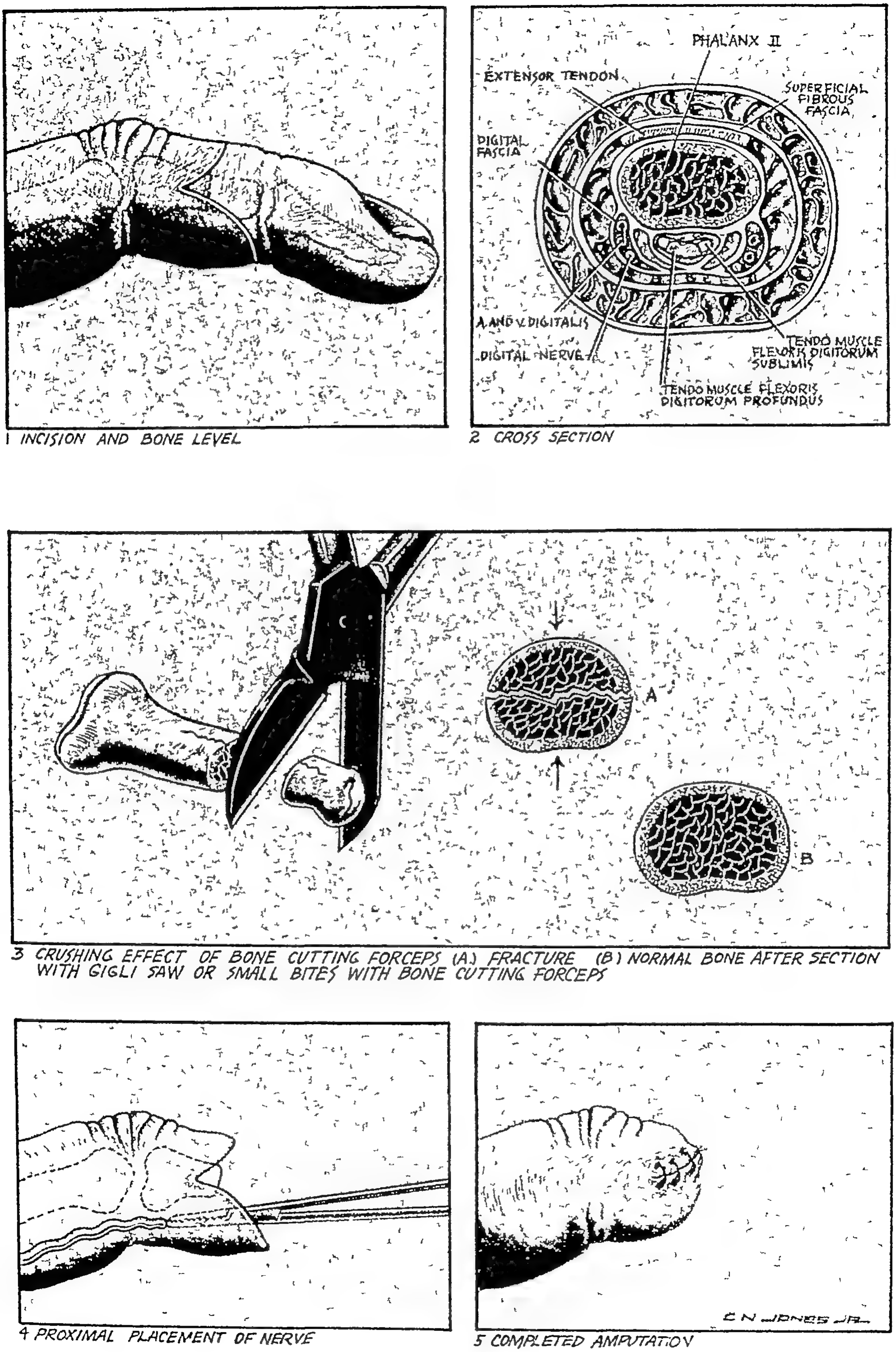

Fig 158.—Amputation through the finger

The periosteum is cleanly severed just above the bone end Care is taken to leave no tags of periosteal tissue No attempt is made to remove a formal periosteal cuff

3 **The nerves and vessels** The nerves lie in the palmar lateral aspect of the fingers They are isolated from their beds and sectioned In the finger the nerve bed is spread with mosquito forceps and the nerves placed proximally one centimeter or so above the bone end If the amputation is through the base of the finger near the palm, the nerves are tucked proximally in the lumbricale canal to prevent neuromata near the end of the stump With the nerves placed in such a position, neuromata if they should form, will be less susceptible to trauma No particular advantage has been found in injecting the nerves with alcohol or other substances in an attempt to avert neuromata formation The best precautionary measure is to cut the nerves cleanly with a sharp blade The blood vessels are simply cut and tied in the usual manner

4 **Closure** The skin flaps are then approximated and fixed with fine interrupted sutures It will be noted that the suture line falls well posteriorly A snug pressure dressing is applied Elevation of the hand is preferable during the postoperative period

Multiple Finger Amputations

Multiple finger amputations are usually the inevitable sequelae of trauma and there is seldom any choice as to the necessity of the procedure In the performance of them, the technique is the same as that for amputation of a single digit, but the preservation of function presents a more formidable problem Consideration must be given to the part which each element of the hand plays in the primary functions of grasp, pinch, and hook, and any steps which are taken must be taken in the light of preserving these functions by saving as much of the vital elements as possible

In grasp, strength is dependent upon the ability of the fingers to force an object against the thumb and the palm, and stability is dependent upon the number of fingers present, and upon the span of the fingers and the breadth of the palm It is evident therefore that the efficiency of grasp will be affected by (1) the number of fingers lost, (2) the strength and position of the fingers lost, and (3) any decrease in the breadth of the palm The first point, the effect of numerical loss, demands no comment for it is self-evident The second, the relative strength and position of the fingers, however, needs further amplification The middle finger and the index finger are the strongest of the digits, and they are the most stable because of their fixation at their metacarpophalangeal joints, these attributes in conjunction with their position give them the leading role in forcing an object against the thumb and the palm—in addition, the index finger as a polar element is a primary factor in span, therefore, as much as possible of both of these fingers should be retained, for if they are gone the hand will lack both strength and stability of grasp The ring and little fingers are much weaker and much more mobile than the index and middle fingers, but their very mobility allows the hand to encompass an object more thoroughly, and their position fills out the span of the hand, thus, though their loss does not rob grasp of the greatest part of its strength, it does materially lessen its stability Amputation of the ring and middle fingers in combination results in loss of the central force contributed to grasp by the strong middle finger, and, though it does not actually lessen the span since the two polar elements remain, leaves a large gap through which objects tend to fall The loss of the little and index fingers together lessens the strength of grasp by depriving it of the strong index finger,

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Fig 159—Amputation of the index and middle fingers at the metacarpophalangeal joint Note the stabilizing effect which the breadth of the palm has upon grasp (Official U S Signal Corps Photo Courtesy of J Bone & Joint Surg 26 535, 1944)

Fig 160—Amputation of the index and middle fingers at the metacarpophalangeal joint, and the thumb at the level of the interphalangeal joint The loss of the thenar ray results in increasing instability in grasp (Official U S Signal Corps Photo)

Fig 161—Partial amputation of the fourth and fifth fingers Grasp is made weak and unstable by the shortening of the ulnar two fingers (Official U S Signal Corps Photo)

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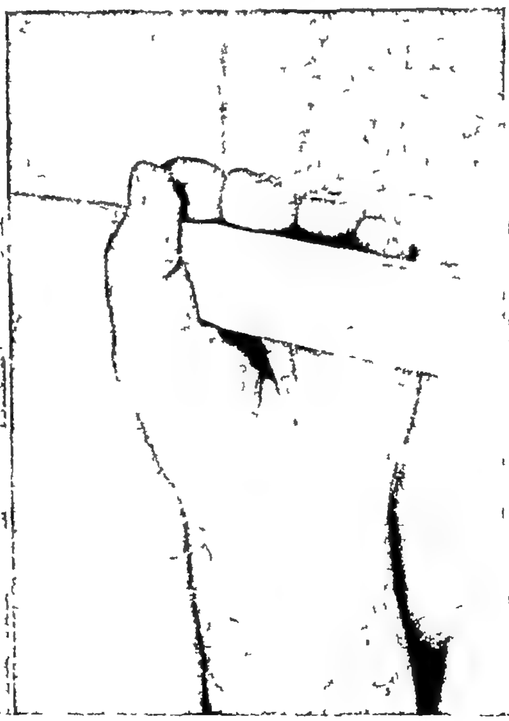

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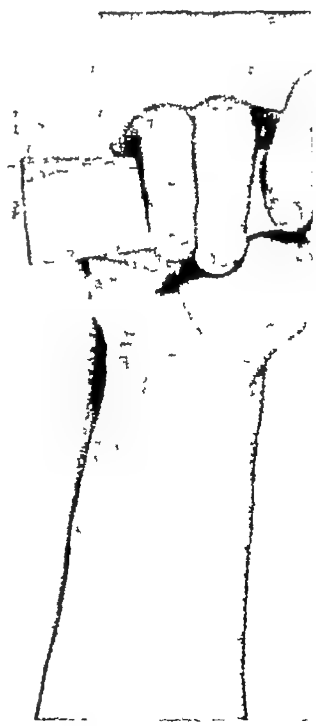

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Fig 162—Partial amputation of the middle and ring fingers Note that grasp remains stable because of the presence of the two polar elements, the index and the little fingers (Official U S Signal Corps Photo Courtesy of J Bone & Joint Surg 26 535, 1944)

Fig 163—Multiple finger amputations Grasp is poor, hook and pinch are practically lost (Official U S Signal Corps Photo Courtesy of J Bone & Joint Surg 26 535, 1944)

Fig 164—Amputation of middle finger at the metacarpophalangeal joint Much of the power of grasp is lost when the powerful middle finger is removed Note the space created between the index and ring fingers which allows small objects to fall through the clenched hand (Official U S Signal Corps Photo)

and materially decreases its stability by eliminating the two polar elements which normally complete the span There are, of course, many other combinations of amputation of two or more fingers, these are too numerous to be dealt with in detail here, but their effects upon grasp can readily be understood in the light of the preceding examples The third factor which affects the efficiency of grasp, the breadth of the palm, becomes a matter of concern only when amputation of the fingers must extend beyond the metacarpophalangeal joints This will be discussed under amputation through the metacarpals, and is only pertinent here as a word of warning—when the demand of occupation or cosmesis would seem to indicate the removal of two or more fingers through the metacarpals it should be remembered that the stability of grasp will be materially weakened

In pinch, the apposition of the tip of the thumb against the pads of the opposing fingers, the value of each finger is in proportion to its proximity to the thumb - the index is the most valuable, and the little finger the least

In hook action, the ability to flex the fingers around an object is required Here the length, number, and mobility of the remaining digits are the primary factors

In summary, let it be said that when two or three fingers must be amputated in combination, the degree of usefulness of the reconstructed hand will depend upon the number, strength, position, and mobility of the remaining elements and the careful consideration of these factors during surgical reconstruction When multiple amputations involving all fingers must be performed, the usefulness of the hand will be minimal, although some function can always be obtained if sufficient metacarpal length is left for a web space to be created between the fingers and thumb

Amputation of a Single Finger Through the Metacarpal

The Index Finger Metacarpal

The index is the most important of the fingers Its position next to the thumb makes it the primary finger in pinch and one of the two polar elements responsible for the wide spread in grasp The stability of its base at the metacarpocarpal joint, and the fact that it is in a nearly direct line of pull of the flexor tendons, makes it second only to the middle finger in power Needless to say, a finger of such value should be preserved if it possibly can be, for the greater the loss of finger length, the greater will be the loss of pinch and, to a lesser extent, grasp When amputation of the index finger occurs above the proximal interphalangeal joint, its pinch action disappears and is substituted for by the middle finger Not only is pinch lost, but it may actually be interfered with by the presence of an index finger in the web space between the thumb and the middle digit which is now the primary pinch finger In many individuals in whom loss of fine movement is unimportant, this protruding stump will be no cause for concern In fact, its presence will enhance the strength and stability of the palm This is particularly true of laborers In many others, however, the short stump will be associated with awkwardness, frequent bruising, and pain In this group, excision of the index metacarpal should be considered in order to obtain the maximum of agility and fine movement of the hand In addition to the removal of an impediment from the web, the cosmetic appearance is so improved that the loss of the finger cannot be detected by casual observation

Technique

1 *The incision* starts on the palmar aspect in the web between the middle and index fingers, and passes radially about one-fourth inch proximal to the

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Fig 165—Amputation of the index finger at the proximal interphalangeal joint The middle finger substitutes for the index finger in pinch, when the latter has been amputated at this level The remaining stump adds to the stability of grasp but often results in awkwardness because it forms an impediment in the web space (Official U S Signal Corps Photo)

Fig 166—Amputation of the index finger just proximal to the metacarpal head Section of the metacarpal at this level allows the distal end of that bone to protrude into the web space and cause pain during grasp (Official U S Signal Corps Photo)

Fig 167—X ray of same case showing improper level of amputation of the index metacarpal (Official U S Signal Corps Photo)

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Fig 168—X ray showing most distal level at which amputation of the metacarpal is satisfactory (Official U S Signal Corps Photo)

Fig 169—Same case showing excellent functional and cosmetic results in amputation through the base of the index metacarpal (Official U S Signal Corps Photo)

Fig 170—Side view of an amputation through the base of the index metacarpal, showing scar position Note the posterior position of the scar which places it well away from the web space and the grasping areas of the hand (Official U S Signal Corps Photo)

flexor crease It then passes medially across the dorsal aspect to the ulnar side of the index finger metacarpal head A second limb of the incision starts on the dorsal aspect at the ulnar side of the index finger at the point of origin of the first incision and passes proximally along the ulnar side of the metacarpal to its base This incision affords wide exposure of the second metacarpal extending to its base and places the suture line well away from the web which is being created so that is cannot form an impediment to function through cicatricial contracture

2 *The bone* is sectioned near the base of the metacarpal If it is divided in its mid-section or more distalward, the bone end will project beneath the skin and will be a tender and painful impediment in the web Since the stabilizing effect of the transverse metacarpal ligament is lost, the index metacarpal is no longer bound to the middle finger metacarpal and, therefore, would contribute nothing to the breadth and stability of the palm by its presence

The finger is removed by section of the soft tissues Digital nerves are cleanly divided by a sharp knife and tucked proximally in their beds for one-half inch Hemostasis is secured The soft tissues are approximated with 000 catgut, and the skin is closed by interrupted sutures A dry dressing with mild compression is applied Stitches are removed on the tenth to twelfth day

When the wound is healed, active use of the hand is encouraged The patient should return to full activity within three to four weeks

The Third or Fourth Finger Metacarpal

Amputation of either the third or fourth finger through the metacarpal results in one of the most serious disabilities of the hand The architecture of the hand is so designed that each metacarpal head is braced against its neighbor, and firmly fixed by the transverse metacarpal ligaments When amputation occurs above these stabilizing bands, rotatory disturbances of the adjacent fingers occur In the normal hand it will be noted that when each finger is flexed individually, the finger tip points toward the tubercle of the navicular bone In contradistinction, when amputation above the transverse metacarpal ligament occurs, the adjacent fingers will be found to rotate either toward or away from the amputated metacarpal, usually the latter The problems arising in reconstruction of this amputation are (1) the correction of the rotatory deformity, (2) the maintenance of the breadth of the palm, (3) the closure of the space intervening between the two adjacent unamputated fingers, (4) the preservation of the intrinsic muscles of the hand where possible, and (5) the cosmetic restoration of the hand

It is obvious that no one procedure can accomplish all of these ends Several have been devised, each adaptable to a particular situation For these the writer takes no credit They are for the most part the work of many different men, and chiefly based on unpublished work

For the sake of simplicity the procedures will be described with relation to the ring finger Variations applicable to the middle finger will be recounted also

1 Complete excision of the metacarpal

Complete excision of the metacarpal has been the classic method of treatment The principle involved is the *approximation of the two metacarpal heads* lying on either side of the amputated metacarpal, and the formation of a new *transverse metacarpal ligament of scar tissue* The result is a cosmetically improved hand with a narrowed palm in which some deformity usually persists

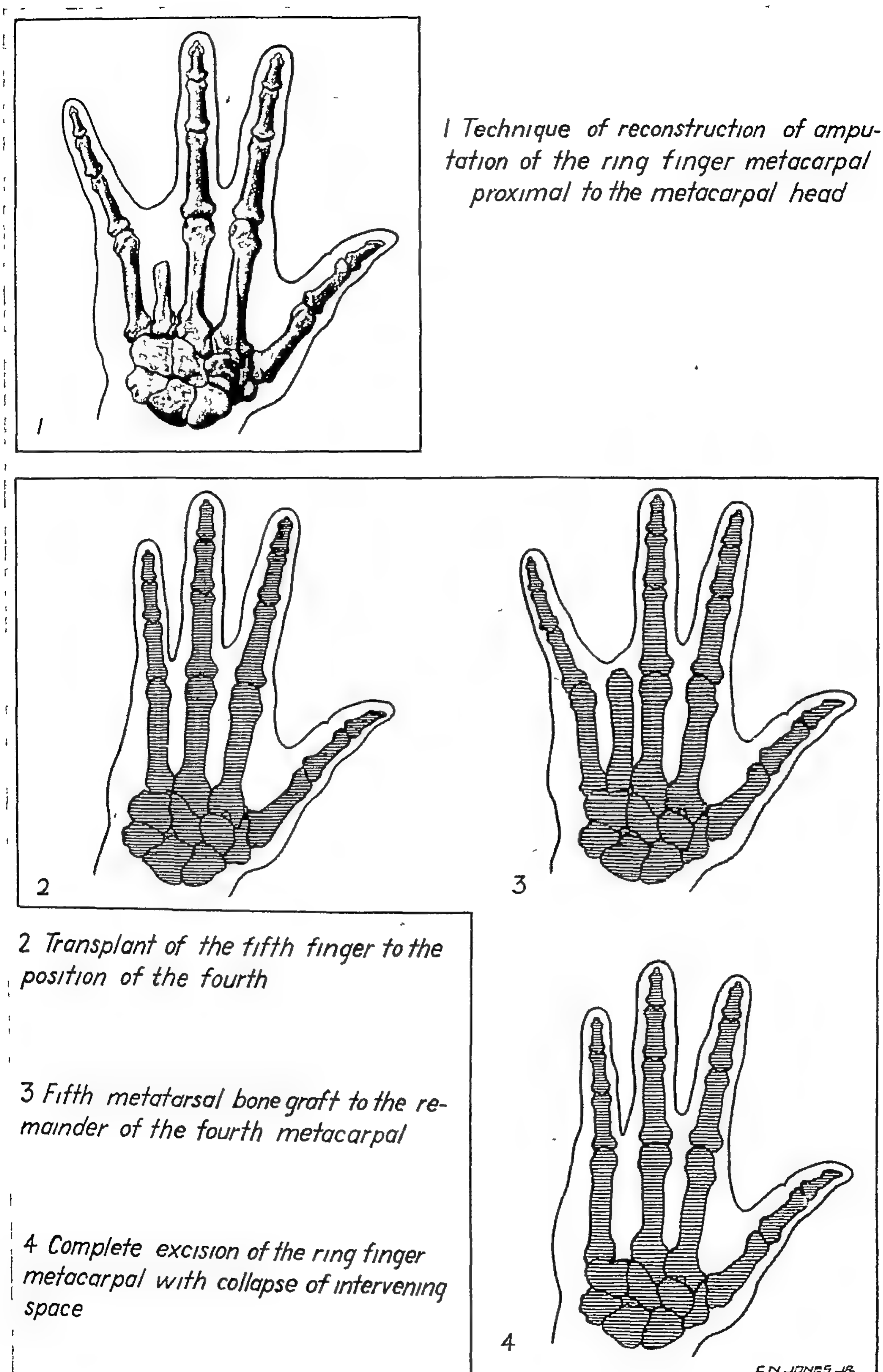


Fig 171 —Reconstruction of amputation of the ring finger through the metacarpal

TECHNIQUE

A dorsal longitudinal incision is made from the level of the metacarpal head to its base The bone is exposed and removed extraperiosteally by sharp dissection The wound is débrided as much as possible of all scar tissue The heads of the two adjacent metacarpals are then approximated by lateral pressure, and fixed by means of fine, plain catgut suture to insure fibrous fixation The soft tissues are brought together by fine catgut The skin is closed by interrupted sutures The technique is varied in the middle finger metacarpal only in that the insertion of the extensor carpi radialis brevis is fixed to adjacent bony structures

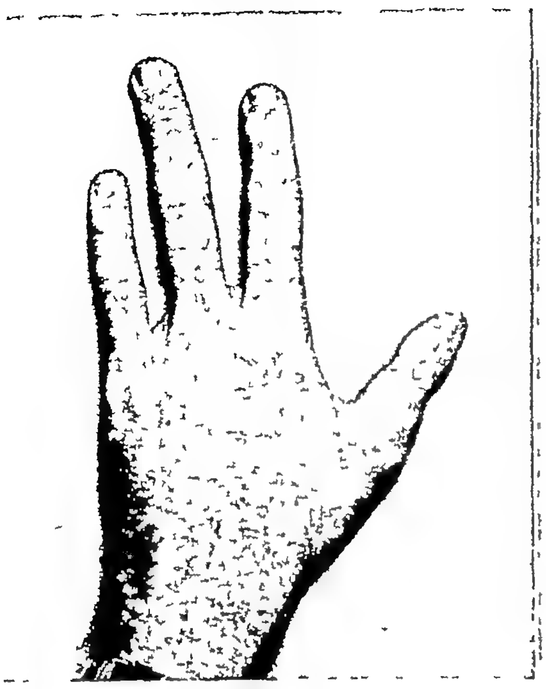
2 **Finger transplant**

a *Transplant of the little finger to the position of the ring finger* This is a more anatomic method of reconstruction than metacarpal excision The principle followed is the approximation of the metacarpal heads by shifting the entire shaft of the fifth metacarpal into the position formerly occupied by the fourth metacarpal The collapse of dead space is more easily accomplished by this method The procedure is made possible by the fact that the carpal articulation of both the fourth and fifth metacarpals rests on a narrow base on the hamate bone which permits the normal range of motion at these joints After transplant, the fifth finger adapts itself well to the normal articulating surface of the fourth metacarpal on the hamate bone with but slight incongruity

TECHNIQUE The fifth metacarpal and the remnants of the fourth are exposed through a dorsal longitudinal incision extending along the interspace between them from the metacarpal heads to their bases The partially amputated fourth metacarpal is excised in toto, and its bed is débrided of all scar tissue. The ligamentous fixation of the fifth metacarpal is then severed at its hamate attachment Restricting bands of soft tissue are freed It is then shifted to the position of the fourth Ligamentous attachments are reattached to the hamate by fine, plain catgut suture The heads of the third and fifth metacarpals are fixed in a similar manner Subcutaneous closure is effected by fine, plain catgut sutures, and the skin is fixed by interrupted skin sutures

b *Transplant of the index finger to the position of the middle finger* When this operation is performed, the web space between the thumb and index finger is increased, and the palm is somewhat narrowed, but the index finger still maintains its important position in relation to the thumb and other digits and its normal functions are retained The metacarpal arch is reinforced, and the rotation of the index and fourth fingers is averted Although the principle of this procedure is the same as that involved in transplanting the fifth metacarpal to the position of the fourth, its execution is somewhat different Anatomically the articulations of the second and third metacarpals with the carpus are irregular, making them relatively fixed This fact argues against shift of the whole metacarpal unless arthrodesis of the base to the carpus is performed Less damaging than this is the transplant and fixation of the distal one-half to two-thirds of the second metacarpal to the proximal stump of the third metacarpal

TECHNIQUE Through a one-inch longitudinal incision on the posterior radial aspect of the second metacarpal, the bone is exposed and sectioned at its base in accordance with the principles of index finger amputation A second incision is then made on the dorsal aspect of the third metacarpal exposing its entire length posteriorly That bone is next resected at a point where it bleeds normally and its medullary canal is intact A second section of the index



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Figs 172 and 173 —Complete excision of the ring finger metacarpal

Fig 172—Note the line of incision on the dorsum of the hand, and the narrowing of the hand (England General Hospital SA475)

Fig 173—Note the normal flexion of the middle finger (England General Hospital SA476)

Fig 174—Complete excision of the middle finger metacarpal at the level of the carpometacarpal joint, with some rotation deformity (Official U S Signal Corps Photo)

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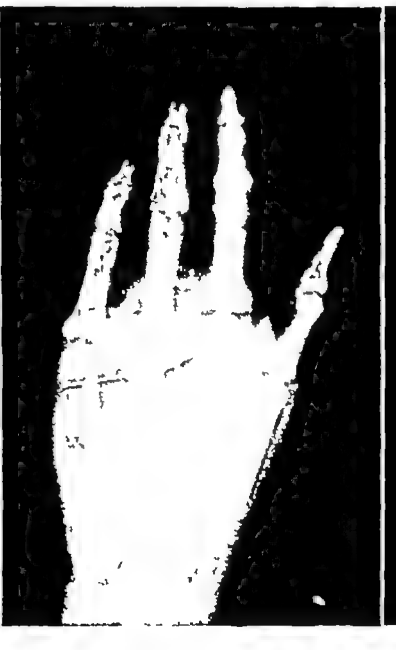

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Figs 175 177—X-rays demonstrating traumatic loss of ring finger at the base of the metacarpal and partial loss of the middle finger metacarpal, treated by transplantation of the little finger to the position of the ring finger, and transplantation of the fifth metatarsal bone of the foot to substitute for the middle metacarpal Case operated by Dr Sterling Bunnel (Walter Reed General Hospital Neg No 4331-A1 and 4382-A2,3)

metacarpal is now made to conform with the level of section of the third metacarpal The space between the dorsal and palmar interossei lying between the two metacarpals is now developed, and the second metacarpal is brought through the interval and approximated to the proximal end of the third metacarpal Fixation is carried out by any of the usual methods The writer prefers an intermedullary peg made from the discarded portion of the second metacarpal and fixation of the distal fragment by transverse Kirschner wires impaling the adjacent metacarpal Closure is effected in the usual manner A cast is applied for five to six weeks to allow union of the bone ends

c *Transplant of the fifth metatarsal to substitute for the amputated portion of the fourth metacarpal* This may be accomplished according to the principles of bone grafting This method fills the palmar gap, minimizes the rotation of adjacent fingers, and maintains the breadth of the palm The gap between the third and fifth fingers remains with the disadvantage in grasping small objects The cosmetic appearance of the hand is less satisfactory than in the finger shifting operations

TECHNIQUE Ample skin must be available Through a dorsal longitudinal incision the remaining metacarpal stump is exposed and resected to healthy bone All scar is débrided from the wound to allow for more ready vascularization of the graft The donor site on the foot is approached through a dorsal longitudinal incision extending from the head of the fifth metatarsal to a point just distal to its base The required amount of bone is removed subperiosteally The metatarsal head is freed of ligamentous attachments and disarticulated The wound is collapsed and subcutaneous tissues are sutured by interrupted fine catgut The skin closure is effected by interrupted skin sutures The metatarsal head and shaft are then placed in the prepared bed, and the bone is fixed by a No 28 stainless steel wire mattress suture, with or without a step cut in the bones, or by other methods such as the peg or chip bone grafts, or intramedullary implantation The skin and subcutaneous tissues are closed in the usual manner, with special care being taken to avoid tight suture of the skin or exposure of the transplanted bone

d *The middle or ring finger* may upon occasion be amputated and used to fill a defect in its own metacarpal

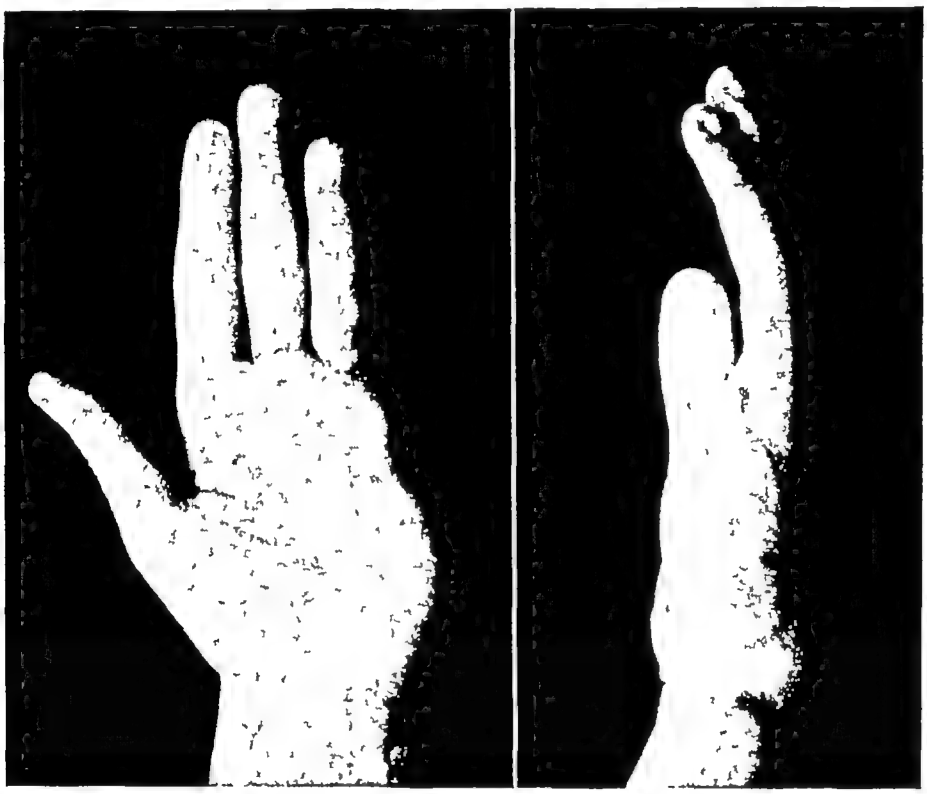
Often single or multiple metacarpal defects exist without undue impairment of function Sometimes, however, they must be filled When it is the middle or the ring finger metacarpal which is defective and the finger itself is still present, the following method, described by L D Howard, will occasionally prove useful It utilizes the principle of amputating the finger at the proximal interphalangeal joint and substituting its proximal phalanx for the defect in the distal metacarpal

TECHNIQUE Through the usual dorsal longitudinal incision, the proximal fragment of the involved metacarpal is exposed and freshened to healthy bone Its end is fashioned into a wedge in the transverse plane The proximal phalanx of the same finger is filleted extraperiosteally Care is taken to leave the soft tissues at the distal end of the phalanx in order to preserve the blood supply The proximal articular cartilage is removed, and a transverse slot is fashioned to receive the wedged metacarpal The proximal phalanx is shifted upward to the metacarpal and fixed with a single wire loop The finger is disarticulated at the proximal interphalangeal joint, the joint cartilage removed, and the distal portion discarded Care is taken to preserve a flap of volar skin to cover the stump If redundant skin remains following this procedure, it may be removed by plastic repair after six weeks

The Fifth Finger Metacarpal

There are those to whom the shortened finger left by amputation above the proximal interphalangeal joint will be satisfactory, but there are some to whom it will prove a hindrance, and others who will deem it unsightly. In these latter cases, its removal is indicated on the basis of function and appearance.

In laborers where function is the primary factor, amputation should be carried out at the level of the base of the proximal phalanx or at the metacarpal phalangeal joint, thus conserving the breadth of the palm. If amputation of the fifth metacarpal, itself, is necessary, maximum length should be preserved. In this situation, there is no web to be interfered with, and the remaining metacarpal affords a base for the attachment of the adjacent intrinsic muscles. Since the ulnar side of the hand is far more mobile in construction than the radial side, the bone may be left long without detriment.



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Figs. 178 and 179.—Amputation of the fifth metacarpal at the level of the mid shaft. Note the line of incision, and the even contour of the ulnar side of the hand. (Walter Reed General Hospital Neg. No. 4650 2,1.)

When cosmesis is the sole consideration, the metacarpal is amputated in the midshaft. The bone end is beveled on the ulnar side, and the skin flap is fashioned to form a gently rounded hypothenar eminence.

TECHNIQUE. Starting over the radial border at the proximal end of the fifth metacarpal, the dorsal incision extends distally through the web space between the fourth and fifth fingers, and passes ulnarward across the proximal flexor crease of the fifth finger and then obliquely backward to the dorsum of the hand to join the first incision at its mid-dorsal portion. This racquet incision may be placed higher in cases where there is less metacarpal length. The bone is now exposed, and the distal portion removed at the level selected. The bone end is beveled on the ulnar side. Digital nerves are isolated and sectioned. Skin

is closed in the usual manner It will be noted that the surgical scar is now over the dorsum of the hand, and that the hypothenar eminence is padded with tough palmar skin

The Thumb

The thumb is the most useful single digit in the hand Its purpose is to serve the hand in grasp and pinch, and its loss results in a quite useless extremity in which only minor substitutionary movements remain Needless to say, every fraction of an inch of length lost through amputation diminishes its effectiveness "Save all possible length" has become the most important dictum in surgery of the thumb The only indication for partial or complete amputation of the thumb is loss of blood supply This is in contradistinction to amputation of the finger where devastation of two or more important structures may be a basis for removal In the thumb, conservative treatment should be followed, with every effort made to preserve and reconstruct any affected structures Such efforts are usually rewarded by functional results superior to those obtained after amputation

Function of the thumb is dependent on length, mobility, muscle power, and sensation When a part of the thumb has been lost, it is the surgeon's irrevocable obligation to preserve these factors in the remaining portion When some loss of them is inevitable, the best use must be made of the remaining structures, and due consideration should be given such reconstructive possibilities as bone graft, nerve graft, tendon substitution, arthrodesis of a joint, etc

In amputation of the tip of the thumb, the general procedures used in amputation of the finger tips are followed namely, reamputation, the use of a skin flap from the palm or trunk, the use of a free full-thickness graft or split-thickness graft, and the flap-shifting method of Woughter, as previously described

Severance at any level between the tip of the thumb and the mid-portion of the proximal phalanx is done in accordance with the standard technique for amputation through the fingers

Amputation About the Metacarpophalangeal Joint of the Thumb

When amputation must be performed at or proximal to the level of the web space between thumb and index finger, the function of the thumb in grasp and pinch becomes almost nonexistent In such a case, it is imperative that all possible length be attained Reconstruction of the thumb by web deepening is the procedure of choice when it will leave a stump long enough to be of practical value, that is, in anatomic terms, when the end of the shortened thumb will lie distal to the head of the first metacarpal bone, and that bone is normal If the thumb is shortened proximal to this point, or if the metacarpal is defective, reconstruction must be accomplished by some other method such as lengthening by the tube pedicle and bone graft procedures, or replacement by transplantation of the index finger

Web Deepening This procedure is carried out for the purpose of both deepening and widening the interosseous space in order that it may afford a grasping area between thumb and index finger It involves the plastic revision of the integument of the space, and the alteration of its structural content

The web between the index finger and thumb is formed by the junction of the palmar and dorsal skin The distal skin fold passes from the level of the metacarpophalangeal joint of the index finger to the mid-portion of the proximal phalanx of the thumb This is most easily demonstrated when the thumb is

abducted The skin is loose and freely movable to insure the motion of the thumb Beneath the skin, filling the interosseous space, lie two large intrinsic muscles On the dorsal aspect is the first dorsal interosseus muscle This strong muscle finds its origins on the proximal two-thirds of the first metacarpal and on the proximal end of the second metacarpal at the dorsal aspect of the web space It proceeds distalward over the radial aspect of the metacarpophalangeal joint of the second finger to join the extensor mechanism of that digit Beneath it lies a potential space of areolar tissue which provides a smooth, gliding surface between the first dorsal interosseus and the adductor of the thumb The adductor pollicis transversus, and the adductor pollicis obliquus of the thumb arise from the palmar aspect of the third metacarpal, and the base of the second metacarpal, and the capitate bone They span the anterior aspect of the web space to insert on the base of the proximal phalanx of the thumb

In order that web deepening may be completed with satisfactory results, three basic requirements must be fulfilled (1) The muscular structures must be released (2) A satisfactory skin covering must be afforded (3) Mobility of the web must be ensured

Treatment of the Muscles of the Web Space After the desired extent of depth is determined, the muscles of the web space are exposed Then detachment is most efficiently carried out by freeing them from their metacarpal and phalangeal elements The first dorsal interosseus is identified at its distal attachment to the first metacarpal, and, by subperiosteal resection, is stripped to a point within one-half inch of the first metacarpal-greater-multangular joint In a similar manner, the adductor policis is stripped from its attachment to the proximal phalanx When freed at these levels, the muscles will still have functional integrity and action There will also be considerable substitution of the thenar muscles for the adductors, whose chief action is to consummate pinch and grasp by forcing the thumb against the fingers Throughout the procedure, care must be taken not to damage the integrity of the radial artery which lies in the depths of the interosseous space No special procedure need be done to the cut attachments of the first dorsal interosseus and adductor muscles, unless they tend to bulge into the space, in which event a stitch is placed to hold them to the proximal end of the first metacarpal

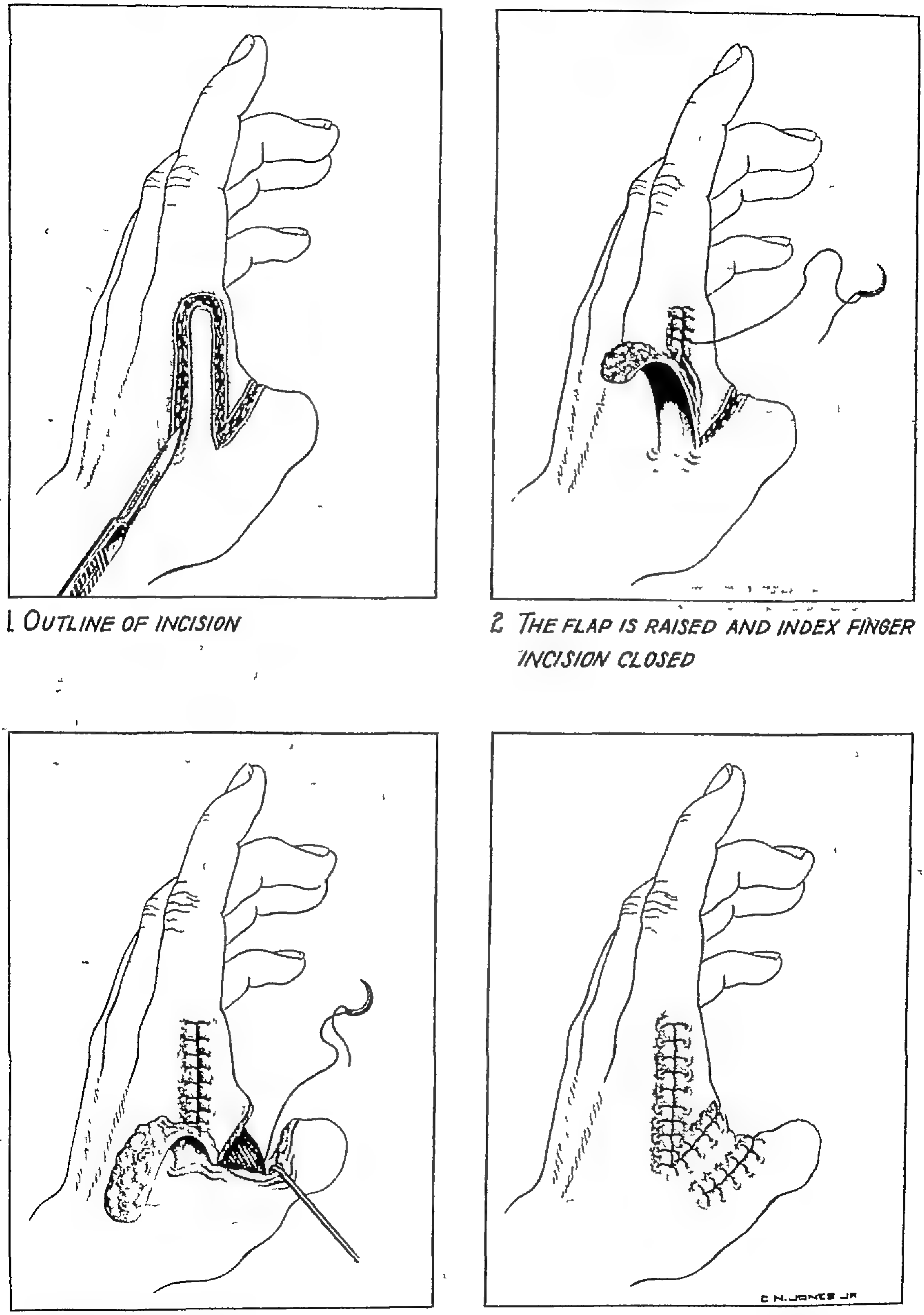
Plastic Rearrangement of the Skin The skin used in the plastic completion of web deepening should have adequate sensation so that it will provide protection from injury during grasp, and should contain a natural fat base so that binding scar may be avoided and mobility of the web achieved The following plastic procedures are the ones usually employed in this operation, and will be discussed in the light of these requirements

1 *The Jump Flap* (Hyroop)

I prefer this excellent method for it provides sensation and mobility with a minimum of undermining and scar It is based on the principle of lifting a flap of normal skin and shifting it to fill a defect The common plastic application of this principle is found in the shifting of a flap from the upper to the lower lid in the repair of eyelid defects It utilizes normal skin with a good layer of subcutaneous fat and excellent circulation

Technique The flap is formed by a long U-shaped incision starting on the posterolateral aspect of the index finger at a point one-half inch distal to the carpometacarpal joint It proceeds downward, paralleling the second metacarpal bone, to the base of the proximal phalanx There it curves radially and proceeds upward along the radial aspect of the second metacarpal, paralleling the original

JUMP FLAP FOR WEB DEEPENING



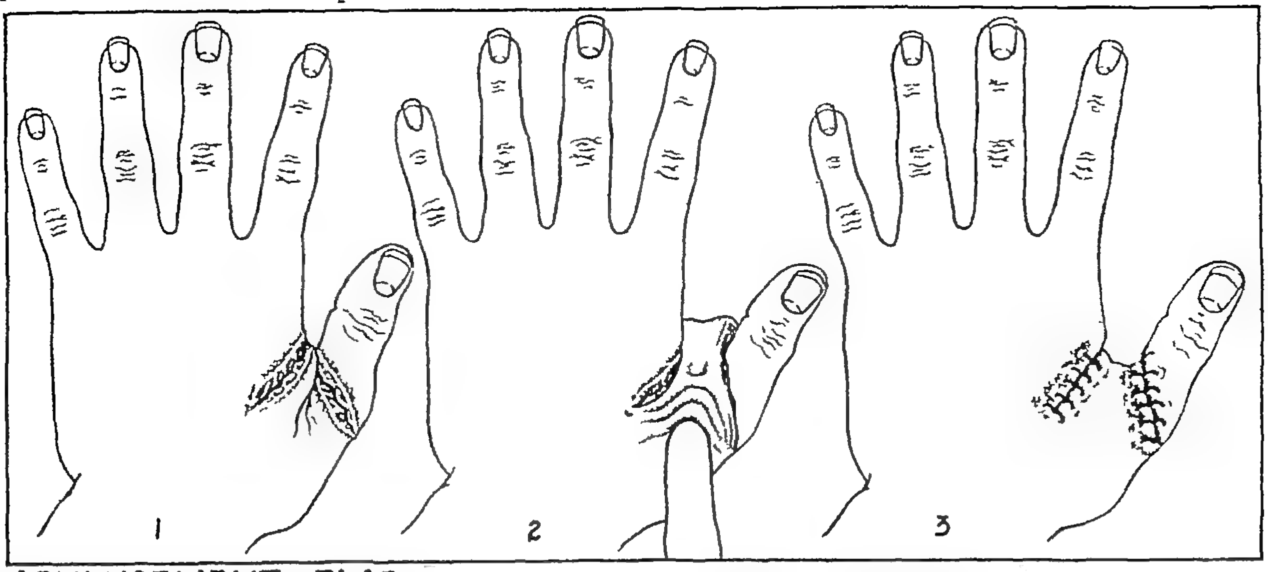
1. OUTLINE OF INCISION

2. THE FLAP IS RAISED AND INDEX FINGER INCISION CLOSED

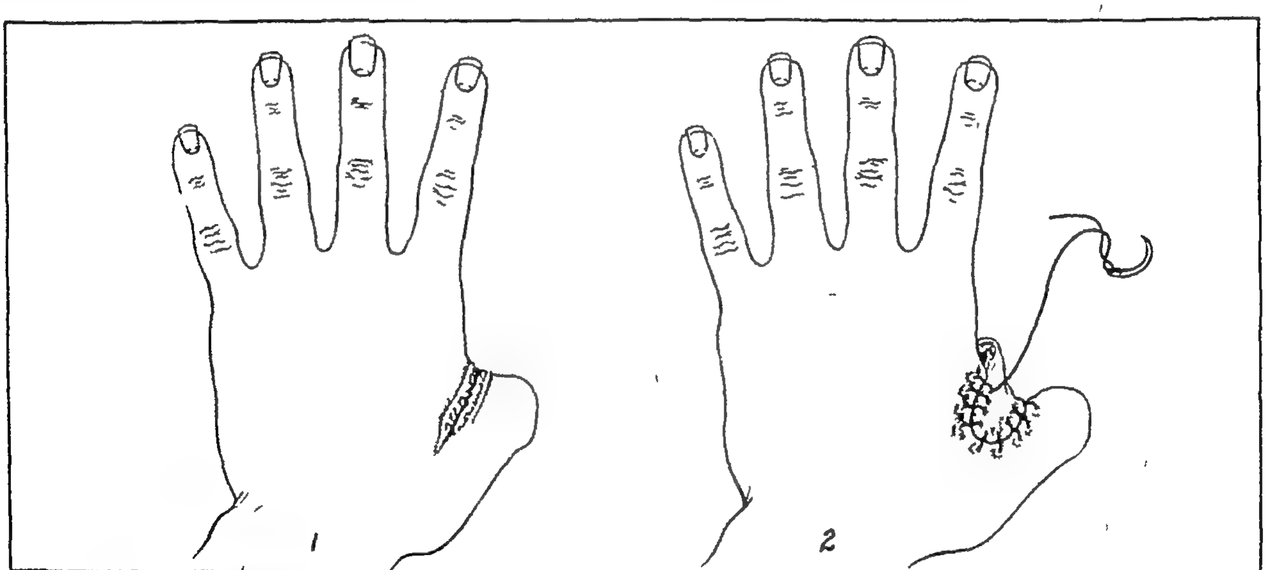
3. THE MUSCLES ARE STRIPPED PROXIMALLY FROM THE DISTAL PART OF THE FIRST METACARPAL AND FIXED

4. THE FLAP IS SUTURED IN POSITION

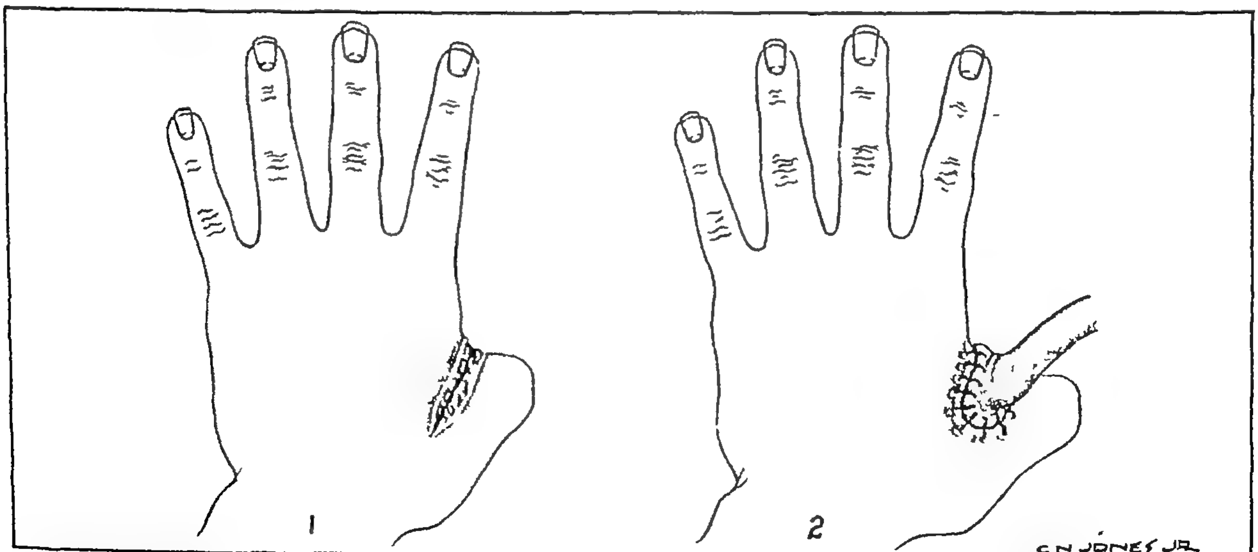
Fig 180



ADVANCEMENT FLAP (1) SKIN INCISED AND FLAP UNDERMINED (2) WEB WIDENED AND FLAP ADVANCED (3) SKIN SUTURED IN POSITION



FREE SKIN GRAFT (1) INCISION (2) WEB DEEPENED AND GRAFT APPLIED



TUBE GRAFT (1) INCISION (2) WEB DEEPENED AND TUBE ATTACHED

Fig 181

incision, to form an elongated "U" about three-quarters of an inch in width. The flap is dissected free. A simple way for the surgeon to judge the proper shape is to lay his index finger over the second metacarpal in the position described and trace the incision around it. An anteroposterior incision is next made across the web space from the palmar surface to the dorsal surface, its length on the palmar aspect being determined by the depth of the web desired. This joins the radial limb of the U-shaped incision at its proximal end. This incision is opened wide. The muscles fixed to the proximal phalanx of the thumb and first metacarpal are removed from their attachments. The flap, previously raised, is now fitted into the defect and fixed with interrupted sutures. The flap bed is closed by side-to-side closure, and fixed by interrupted sutures. In instances where there has been a loss of normal skin tone through atrophy, injury, or disease, a small auxiliary split-thickness skin graft may be necessary to allow closure of the wound on the radial aspect of the index finger.

2. *The Advancement Type of Skin Flap*

When a jump flap cannot be used because of the presence of excessive scar formation in that area, an advancement flap may be substituted. Its principle is the distal advancement of a flap of skin into a space which has been widened and deepened.

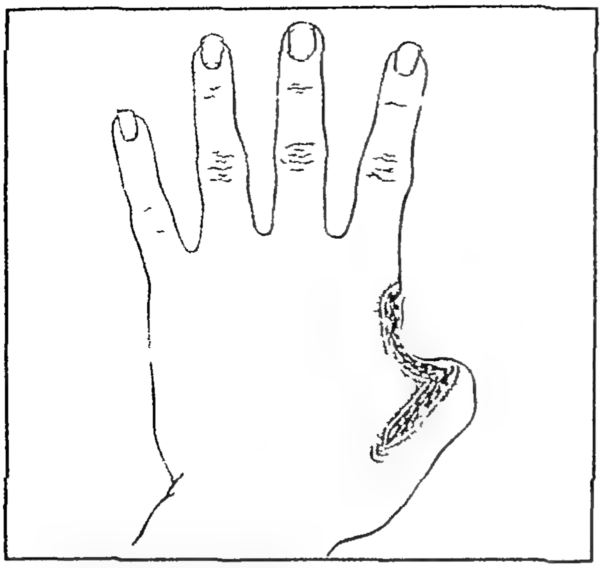
TECHNIQUE. The tip of the flap will vary in width from one-half to three-fourths inches, depending on the tissue available. An incision is made across the transverse fold of skin which represents the highest line across the web when the thumb is abducted. From either end of this a dorsal incision is begun; the one on the radial side will extend to the mid-point of the first metacarpal, and the one on the ulnar aspect to a like point on the second metacarpal. The flap is then reflected backward to facilitate undermining of the surrounding skin between the superficial and deep fascia. The web space is next deepened to the desired level, this requires an anterior skin incision perpendicular to the web to insure proper depth, and the freeing of the muscular attachments of the first dorsal interosseous and adductor pollicis. The flap is now pushed forward, and the tip is sutured to the proximal anterior portion of the wound. The graft is fixed by interrupted sutures of silk or No. 34 stainless steel wire.

3. *The "Z" Plasty*

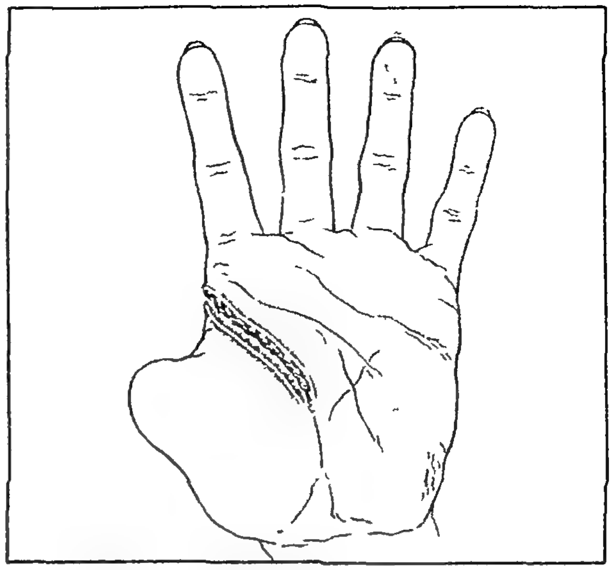
This procedure and its modifications supply skin with good sensation and subcutaneous fat, but they require more extensive undermining of the skin and result in more scar over the palm and second metacarpal.

TECHNIQUE: In planning the flaps of the "Z" plasty, it must be remembered that the shorter the thumb the deeper the web must be, and consequently the greater is the length demanded of the skin flap. The incision starts on the palm of the hand, overlying the base of the third metacarpal, and follows the thenar crease to the radial aspect of the metacarpophalangeal joint of the index finger. From this point the incision runs directly across the web space to the dorsal surface of the thumb. Its height on the thumb depends upon the length of the flaps desired. The incision then passes proximally to a point between the bases of the first and second metacarpal bones. Here, the length of the incision depends upon the desired depth of the web. This results in two triangular flaps—the palmar flap, with its base along the thenar eminence and its apex at the base of the index finger, and the dorsal flap with its base lying across the index metacarpal and its apex over the dorsum of the thumb. The palmar flap is placed dorsally around the thumb so that its apex lies at the proximal end of the base of the dorsal flap. The dorsal flap is swung palmarward so that its

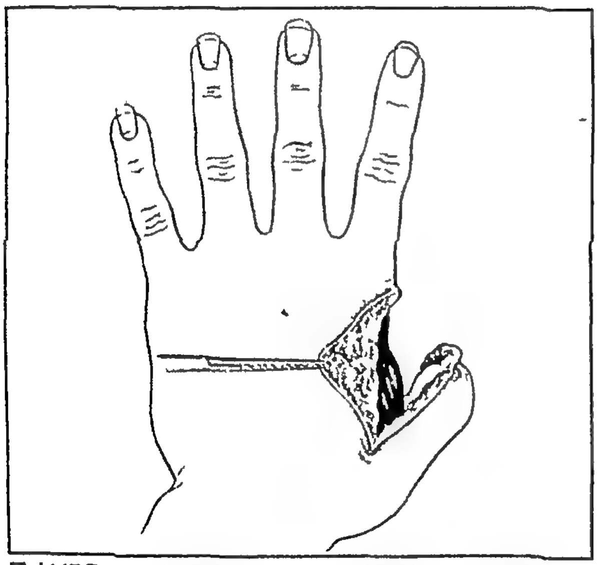
Z-PLASTY



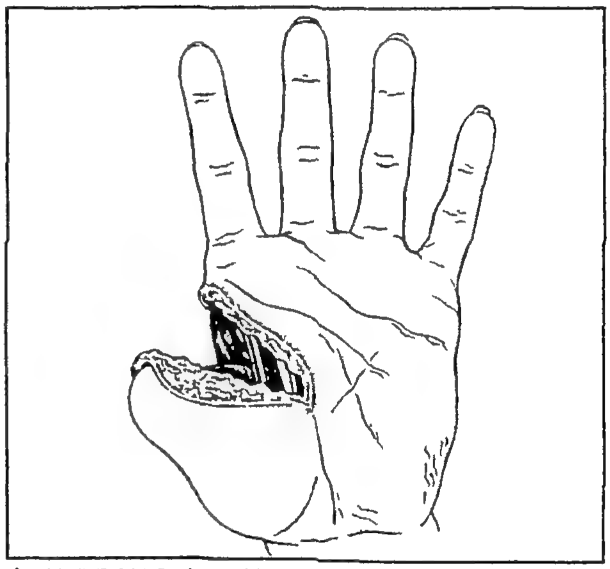
1 POSTERIOR INCISION THE TIPS OF FLAPS ARE AT A 60° ANGLE



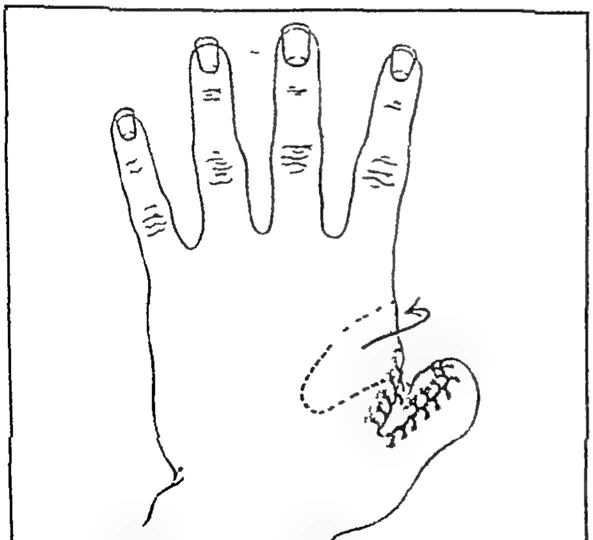
2 ANTERIOR INCISION



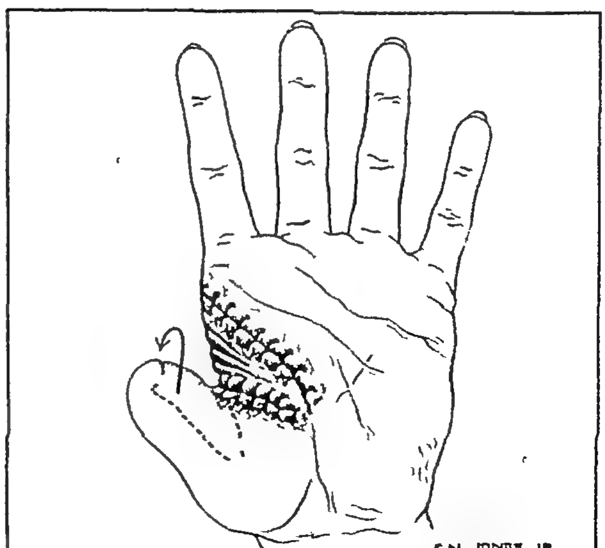
3 WEB DEEPENED, FLAP READY TO SWING



4 ANTERIOR VIEW



5 ANTERIOR FLAP IN FINAL POSITION



6 POSTERIOR FLAP IN FINAL POSITION.

Fig 182

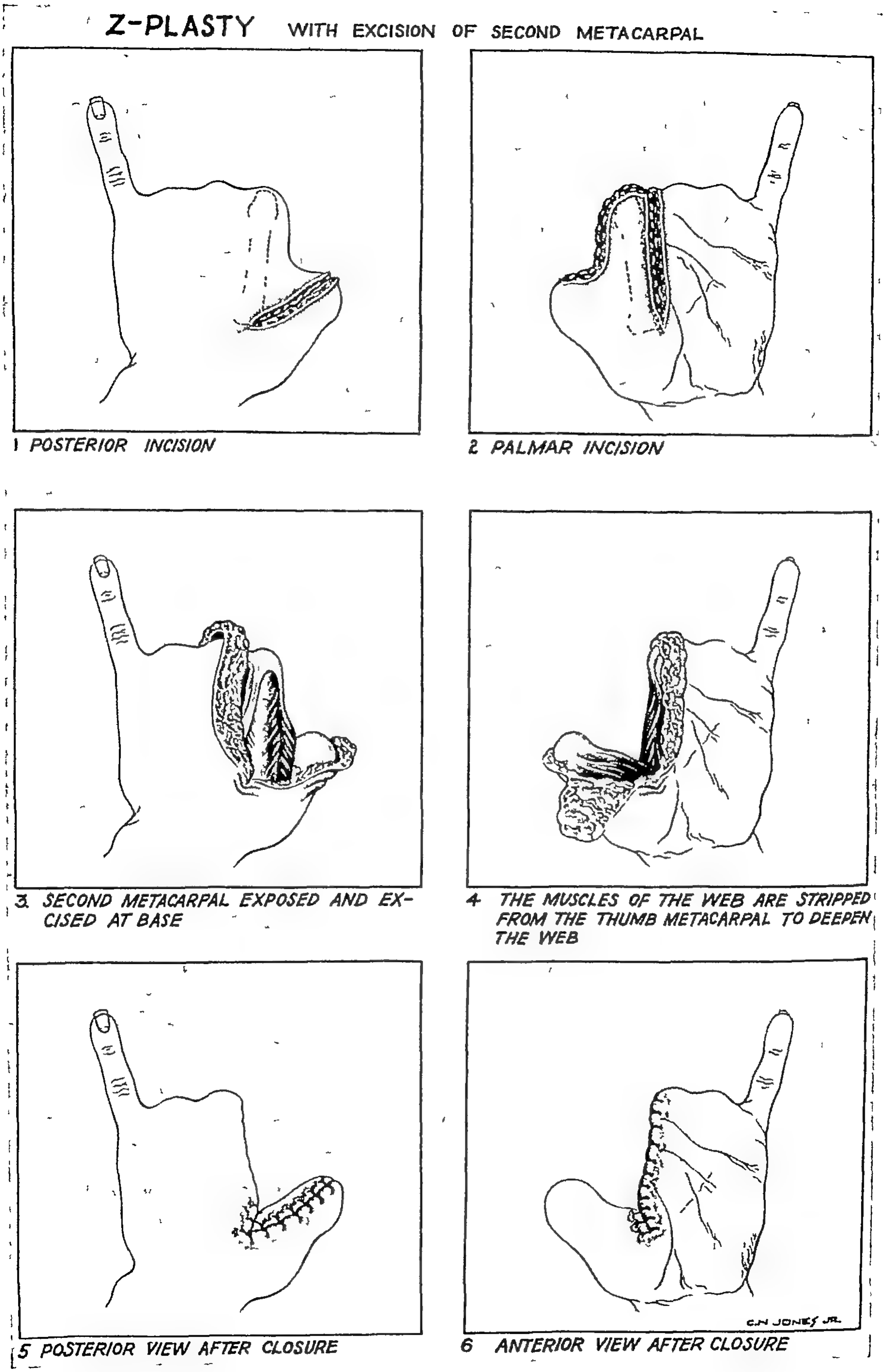

Z-PLASTY WITH EXCISION OF SECOND METACARPAL
1 POSTERIOR INCISION
2 PALMAR INCISION
3 SECOND METACARPAL EXPOSED AND EXCISED AT BASE
4 THE MUSCLES OF THE WEB ARE STRIPPED FROM THE THUMB METACARPAL TO DEEPEN THE WEB
5 POSTERIOR VIEW AFTER CLOSURE
6 ANTERIOR VIEW AFTER CLOSURE
C.N JONES JR.

Fig 183

apex lies at the proximal end of the palmar flap The suture line now lies in the mid-portion of the web, running from anterior to posterior When the interosseous space is widened as well as deepened, a skin defect remains on the dorsum of the thumb This may be covered by a free split-thickness graft Several variations of the "Z" plasty may be used when only a small degree of deepening is desired

4 *The "Z" Plasty With Excision of the Second Metacarpal*

The excision of the second metacarpal in conjunction with the "Z" plasty allows a much wider and deeper web to be created This procedure is indicated when the thumb and index finger are both amputated at the level of the metacarpophalangeal joint and web deepening is required to extend one inch or more proximal to that joint in the thumb

TECHNIQUE The technique of this operation is essentially the same as that just described, with the exception that the palmar incision follows the interosseous space between the index and third metacarpals to the level of the web space instead of following the thenar crease to the radial side of the index metacarpophalangeal joint From the distal end of this longitudinal incision, a second limb passes across the head of the index metacarpal and across the web space to the dorsal aspect of the thumb A third branch of the incision passes proximally along that aspect to end in the interosseous space between the bases of the second and third metacarpals The second metacarpal is then excised at its base, and the tissues of the web space are deepened as previously described The anterior flap is swung about the thumb and sutured with its apex being placed posteriorly The posterior flap is now placed anteriorly so that it covers the radial aspect of the third metacarpal Closure is effected in the usual manner A light compression dressing is applied

5 *The Free Split-Thickness Graft*

This type of graft and the tube or pedicle graft, the description of which is immediately following, lack sensation in the transplanted areas The free split-thickness graft may occasionally be necessary when local plastic procedures are impractical The graft should always be sufficiently thick to insure adequate protective covering, usually of 0 020 to 0 024 cm in thickness in adults, and somewhat less in children

TECHNIQUE The bed for the graft is prepared at the desired depth The skin graft is removed from the donor site and sutured to the periphery of the wound by interrupted silk sutures It is sometimes necessary to place a central suture or two to insure that the graft is held firmly to its bed The wound is dressed with the thumb in abduction, and moderate pressure is applied The dressing is not removed for first observation until the seventh to tenth day

6 *The Tube or Pedicle Flap Graft*

The tube or pedicle grafts contain good subcutaneous fat Their use is indicated when the denuded area is large, and there is extensive local scarring, so that adequate skin cannot be obtained locally, and when fat is needed as padding over bone The standard techniques are employed Flaps are generally preferred to tubes since the time element required for transplant is considerably less

AMPUTATIONS PROXIMAL TO THE HEAD OF THE FIRST METACARPAL

In amputations proximal to the head of the first metacarpal bone, the choice lies between improving the utility and appearance of the stump, and

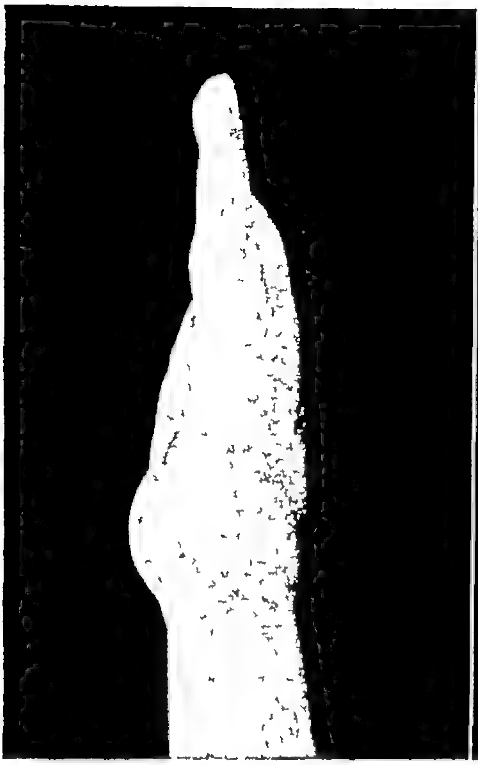


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Fig 184—Plastic repair of the amputation stump at the base of the thumb Skin covering was provided through a skin flap shifted from the dorsum of the hand to the palm The defect on the back of the hand was closed by a split thickness skin graft (Walter Reed General Hospital Neg No 4439 2)

Fig 185—Transplantation of the index finger to the thumb (Walter Reed General Hospital Neg No 4808 2)

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Figs 186 and 187—Reconstruction of the thumb and metacarpus by osteodermal graft The two views demonstrate the range of abduction and adduction This procedure was indicated in this case because of a forearm amputation of the opposite extremity (Courtesy of Dr E C Holscher Lawson General Hospital Neg No 1263)

reconstruction of the thumb In making the choice, the surgeon must take into consideration the psychological make-up of the patient, occupation, whether the arm is the major or the minor one, and whether the functional status of the other arm is normal or impaired

The procedure selected will be one of the following three (1) plastic repair of the amputation stump, (2) transplantation of the index finger to the thumb, and (3) thumb lengthening by osteodermal graft

1 **Plastic Repair**

Plastic repair of the area from which the thumb has been amputated is indicated when the site of amputation is covered with unsightly, fragile, or poorly nourished scar tissue which would break down under minimal trauma, or when there are protruding metacarpal remnants which make the use of the hand awkward and painful It is apparent that no useful function of the thumb will result from such plastic procedures, but the restoration of a satisfactory skin covering will enhance the utility of the remainder of the hand through the elimination of pain and scar tissue, and the general improvement of circulation

Before plastic repair, it is requisite that all bony spurs be removed, and that the osseous elements be trimmed and smoothed to a point where the skin surface provided over it will form an even rounded contour

The repair of the skin itself may frequently be carried out by excision of scar and side-to-side closure after undermining the adjacent skin If a skin defect still remains and the area is small, a free split-thickness skin graft may be used to close the wound More extensive areas, particularly on the palm, are best treated by supplying skin with intact sensation and a layer of subcutaneous tissue This may be accomplished in many instances by undermining and shifting skin adjacent to the defect to close the gap Frequently, however, it will be necessary to transfer a fairly large amount of skin to the denuded area When this is the case, a flap from the dorsum of the hand may be shifted radially over the base of the thumb, and over the adjacent palm when required This flap is better delayed before transfer, for the blood supply of the skin on the dorsum of the hands is not abundant, due to the thin layer of subcutaneous tissue in which the blood vessels travel In order to afford sufficient vascularization in the flap, it is outlined and lifted from its bed, then it is immediately reattached by suture to remain a time before transfer is effected Because of this necessary delay, in cases of acute trauma it is better to use a split-thickness skin graft as temporary cover and undertake final closure by delayed flap at a later date In planning the flap, it must be remembered that the wound to which it is to be transplanted will be enlarged when the cicatricial bands have been released, and allowances for this should be made in the size of the flap, care should also be taken that the direction of the shift will not impair the circulation of the flap by kinking or angulation The flap should be broader at its base than at its apex and should not have a length of greater than twice the base About two weeks after the delaying procedure, the flap is lifted, the scar tissue overlying the base of the thumb is resected, and the flap is sutured in position The defect from which the flap was raised is filled by means of a split-thickness graft Compression dressings, using mechanic's waste or sea sponge, are applied with elastic bandages, and a plaster splint is used to immobilize the hand during healing This method results in an ideal skin covering with intact sensation

Alternate methods are found in the use of the tube pedicle and flap grafts from a donor site on the abdomen These methods are not as satisfactory as the use of a local flap since they are multiple-stage procedures, involve more discom-

for while the hand is fixed to the abdomen, do not supply sensation, and usually have a greater layer of subcutaneous fat which may become unsightly through overgrowth

2 Transplantation of the Index Finger to the Thumb

This is a formidable surgical procedure attended by great risk It should be reserved for cases where the function of the thumb is imperative In the ideal case additional length will be gained, sensation will be intact and joint motion including apposition will be present

a *When the Proximal Part of the First Metacarpal Remains*

The principle of this operation is the transfer of the index finger, intact with sensation and blood supply, to the thumb when the proximal one-half of the first metacarpal remains with intact thenar muscles

TECHNIQUE

Incision On the palmar aspect from a point one inch distal to the distal transverse skin crease of the wrist and between the bases of the second and third metacarpals, the skin incision proceeds distalward to the posterior aspect of the web between the index and the middle fingers It then swings radially over the dorsum of the hand to the radial border of the index metacarpal and thence upward along its posterolateral aspect to the base of the thumb metacarpal If a scar remains over the end of the shortened thumb, it is excised to the radial border of the thumb, if this area is covered with normal skin, an incision is carried transversely over the end of the stump to allow for the attachment of the index finger

Treatment of nerves and vessels The digital nerve supplying the radial aspect of the middle finger and the ulnar half of the index finger is identified and split in the line of cleavage to the level of the transverse carpal ligament in such a manner as to allow the fibers going to each finger to appear as separate nerves The dorsal digital nerve is treated in a similar manner The palmar arch is then identified and is sectioned at a point where the radial artery divides, one branch passing to the index and middle fingers This branch is followed distally to a point where there is an offshoot to the middle finger This offshoot is sectioned and tied It will now be seen that all blood supplied by the radial aspect of the palmar arch passes to the index finger

Treatment of soft tissues The flexor tendons of the index finger are exposed and split from the flexor sublimis and flexor profundus of the adjacent fingers The common extensor of the index finger is freed to the wrist level from its attachment to the common extensor of the other fingers The muscles in the interosseous space are next divided by longitudinal incision in the center of the space

Osteotomy The second metacarpal is now sectioned by means of a step cut A companion step cut is made in the first metacarpal This cut is such that the index finger, when placed upon it, is at right angles to its former position, thus approximating the normal functional position of the thumb The index finger is then transferred to the position of the thumb and fixed by means of mattress stainless steel wire or any other accepted orthopaedic technique

Closure The dorsal flap which was cut long on the radial aspect is now swung to cover the radial aspect of the third metacarpal The skin on the transferred index metacarpal is sutured to the thumb stump circumferentially It will be found that a skin defect is present on the posterior ulnar aspect of the thumb in the metacarpal region This is covered by a split-thickness graft obtained from any available donor site

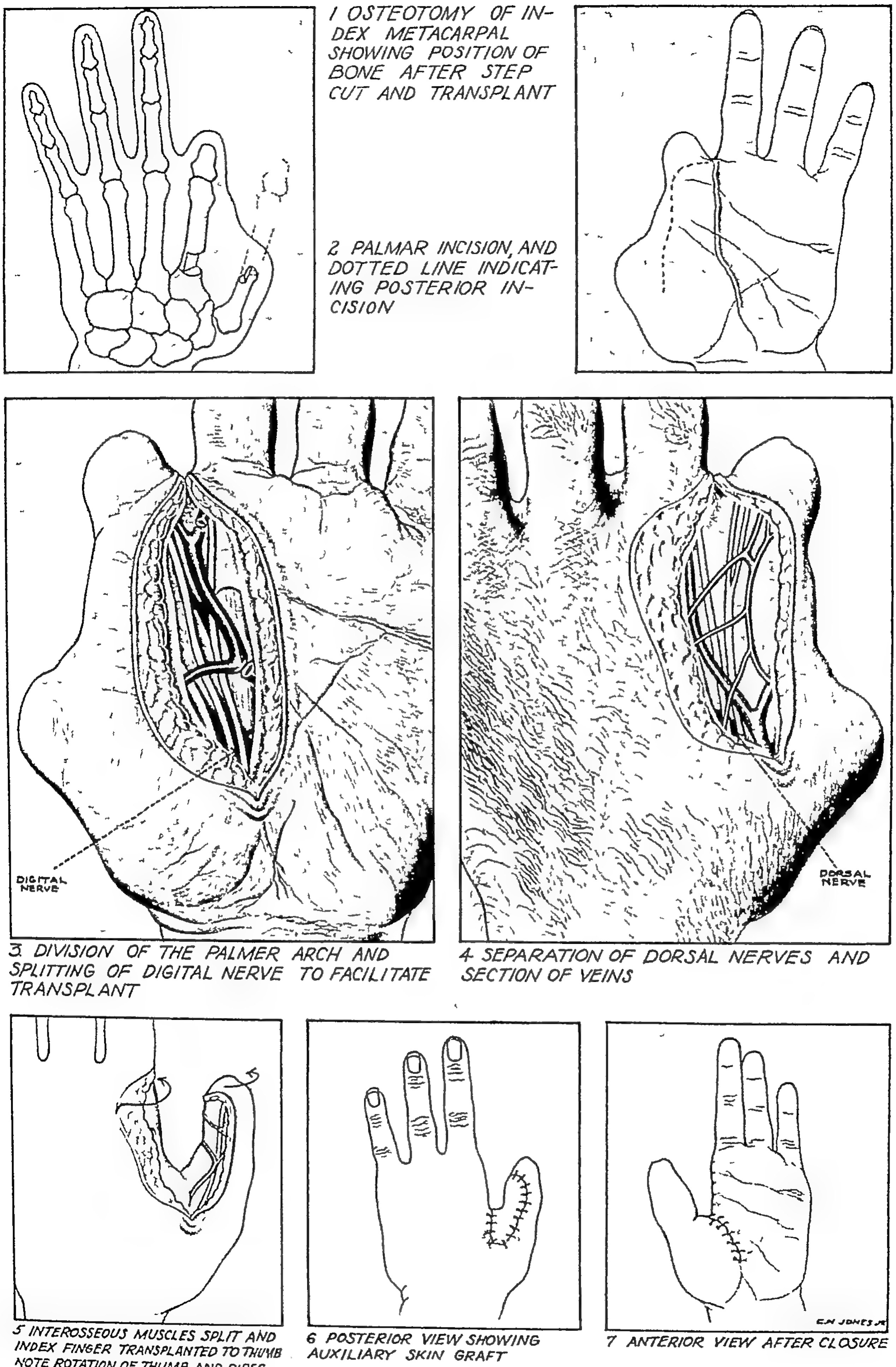


Fig 188 —Transplantation of the index finger to the thumb

The wound is dressed, and a pressure dressing of mechanic's waste fixed by a snug elastic bandage is applied. The hand is immobilized in a plaster of Paris splint. The cast and dressings are removed after a two-week period. The wound is dressed again and a new cast is applied for a period of approximately four weeks. At the end of this period, the cast is removed and physical therapy is instituted.

b. *When the Entire First Metacarpal Is Lost*

Bunnell has described a method of transplanting the index finger when there is total loss of the first metacarpal. The skin flaps are so cut that a dorsal flap will cover the denuded area on the ulnar side of the index finger after transplant. The palmar incision is longitudinal, passing over the space between the index and middle finger metacarpals. The index finger is next separated from the middle finger and disarticulated at its base. It is now transplanted en masse with tendons, nerves, and blood supply, so that the proximal articulation rests on the saddle of the greater multangular. Tendon reattachment and transfer is carried out as necessary to restore the normal motions of the thumb.

3. **Lengthening of the Thumb by Means of an Osteodermal Graft**

A tube skin graft with a supporting bony insert may be of occasional use in replacing an amputated thumb. This operation results in a thumb with only slight sensation, and poor function when compared with other methods. It is usually awkward in use, and frequently impairs the function of other fingers. Appearance leaves much to be desired because of the absence of the nail and the poorly matching skin. The indication for this technique of reconstruction is limited to those cases in which other methods cannot be used but where the demand for even minimal function is great, for example, amputation of the opposite upper extremity.

TECHNIQUE. A tube graft of appropriate length and thickness is formed on the opposite side of the abdomen. It is usually preferable to use one of the techniques, such as that of Bunnell, which displaces the suture line from a position beneath the tube. After two to three weeks, when the tube has established circulation, its medial end is transplanted to the base of the thumb following as thorough a débridement of scar tissue as the situation permits. This base must be large enough to insure adequate vascularization of the tube. After two to three more weeks, the tube is detached from the abdomen and its distal end is closed. Some extra length is usually advisable in case of loss because of impaired circulation at the end of the tube. After the viability of the tube has become established and it is soft and pliable, the tube is reopened through the old suture line, and a bone graft from the tibia is implanted in it with the proximal end impaling the greater multangular. The position of the graft is such that it will place the thumb in moderate opposition and flexion. (In the ideal case the tip of the new thumb will touch the pad of the middle finger in flexion.) The tube is then resutured over the graft, and cast immobilization is applied and retained until bony union is present. Tendons are then supplied as necessary.

The transplantation of fingers or toes from another extremity to replace an amputated digit is not desirable except in rare instances. The loss of sensation leads to trophic changes, lack of function, and ulceration, and annular scarring at the point of attachment to the hand is frequently present.

Amputation of Two or More Metacarpals

Amputation of two or more metacarpals results in serious hand disability. Grasp, pinch, and hook are involved to varying degrees depending on the extent of the injury. The following points should always be considered: (1) the

breadth of the palm should be preserved, (2) an adequate web space should be maintained, (3) two opposing poles consisting of thumb and finger elements should be retained, (4) cosmetic considerations are secondary to function, and (5) formal amputation is seldom possible Flaps must usually be formed from tissues left following injury or radical resection A long palmar and short dorsal flap are preferred

If amputation through the metacarpals of both the index and middle fingers becomes necessary, the metacarpals should be resected at their bases to ensure a satisfactory web In the formation of the web, care should be taken to break the incision by a zig-zag method in order to prevent secondary contracture

In amputation of the metacarpals of index, middle, and ring fingers, the metacarpal bones should be so excised that the web drops in a gradual arc from the fifth finger Enough bone should be resected to avoid protrusion into the web, so that maximum efficiency of the palm will be maintained

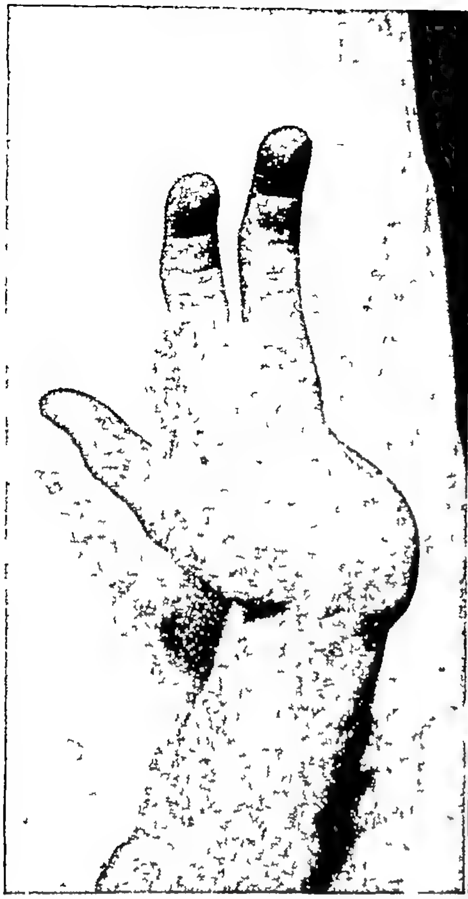
In amputation through the fourth and fifth metacarpals together, the fifth metacarpal should be left slightly shorter than the fourth to improve the cosmetic appearance of the hand and to avoid a projecting bone and under the skin Within this limitation all possible length should be saved The hypothenar eminence should always be preserved, even in instances where the metacarpals are completely resected, since that heavy pad of tissue forms an abutment against which objects can be grasped, and is of importance in pushing

In treating amputation of the middle, ring, and little finger metacarpals in combination, all possible length should be maintained in order to preserve grasp Even though the metacarpals more centrally placed in the hand are shorter than the fifth metacarpal, length should still be conserved in the latter Only when its skin covering is poor or inadequate should the fifth metacarpal be shortened, and even then as much of the hypothenar eminence as possible should be maintained

Amputation of the second through the fifth metacarpals leaves a hand useful only in pushing and in hook action with the thumb It is still more valuable than forearm amputation with a prosthesis

When the thumb is amputated through the metacarpal in combination with the loss of other metacarpals, one of the two valuable pillars for grasp and pinch is gone When the middle and ring fingers are lost in addition to the thumb, the strongest finger elements are missing, and function is even further limited Needless to say, all efforts should be made to preserve a thumb element in combination with finger elements A web space of sufficient amplitude to afford some sort of grasp must be provided if any of this function is to remain

When the thumb and all fingers are missing at the metacarpophalangeal joint level, the hand takes on the appearance of a mitten, and serves only the function of pushing, though there is some hook action with the flexed wrist In order to restore some usefulness, Alldredge and Hulnick, independently, developed a technique for creating a bifid hand capable of opening and closing like a pair of pincers Although unsightly, this amputation is fairly useful, and adapts itself well to a cosmetic prosthesis The principle involved is that of excision of two or more of the central digital rays together with the capitate bone to form a movable thenar and hypothenar post The skin made available by excision of the metacarpal bones is adequate to cover the inner aspects of the newly formed pincers The success of this procedure is based on the excision of the capitate bone, for, without its removal, very little motion can be obtained I consider this a very worth-while procedure for function, but since it is cosmetically in the same category as the Krunkenberg amputation, its popularity will not be widespread



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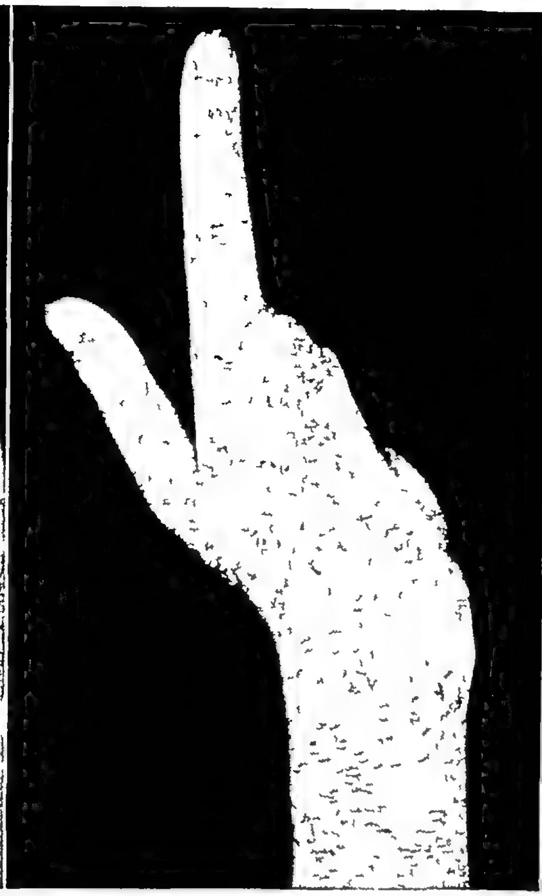

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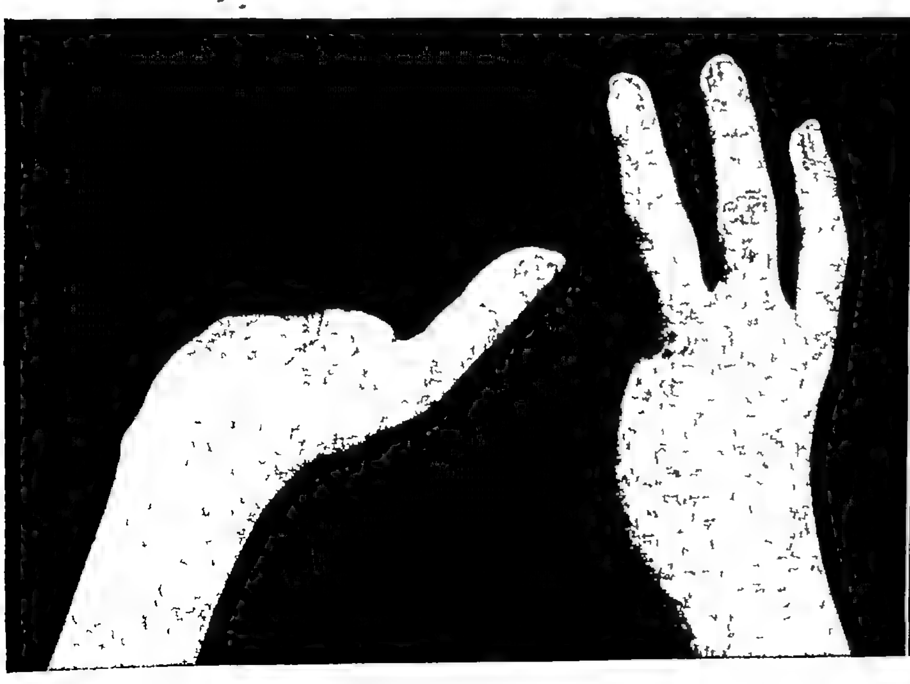
Fig 189—Loss of the ring and little finger rays through disarticulation at the carpometacarpal joints Although the thumb and two strong fingers of the hand remain for grasp, pinch, and hook, grasp is materially weakened because of the loss of the supporting palmar base on the ulnar side of the hand as well as the loss of the fingers Hook action also is moderately weakened (Official U S Signal Corps Photo)

Fig 190—Amputation through the metacarpals of the middle, ring, and little fingers, performed in such a manner that the palm tapers from the base of the index finger to the ulnar border of the hand The stump is covered by tough palmar skin Pinch between thumb and index finger, and hook with the index finger were the primary functions retained in this hand, the remaining palm was valuable for pushing and holding (Walter Reed General Hospital Neg No 4308)

Fig 191—Disarticulation of the index finger at the metacarpophalangeal joint and partial amputation of the middle, ring, and little finger metacarpals Slight pinch between thumb and index metacarpal and pushing and holding with the palm were the sole remaining functions of the hand (Walter Reed General Hospital Neg No 4432 2)



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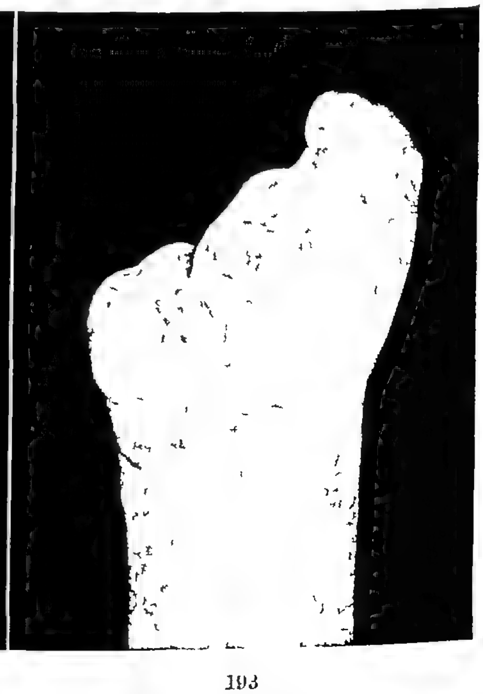

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Fig 192—Bilateral partial hand amputations
and holding functions alone remained

The left hand was amputated through the metacarpals of all four fingers, In the right hand, the thumb and index finger were lost, and the defect

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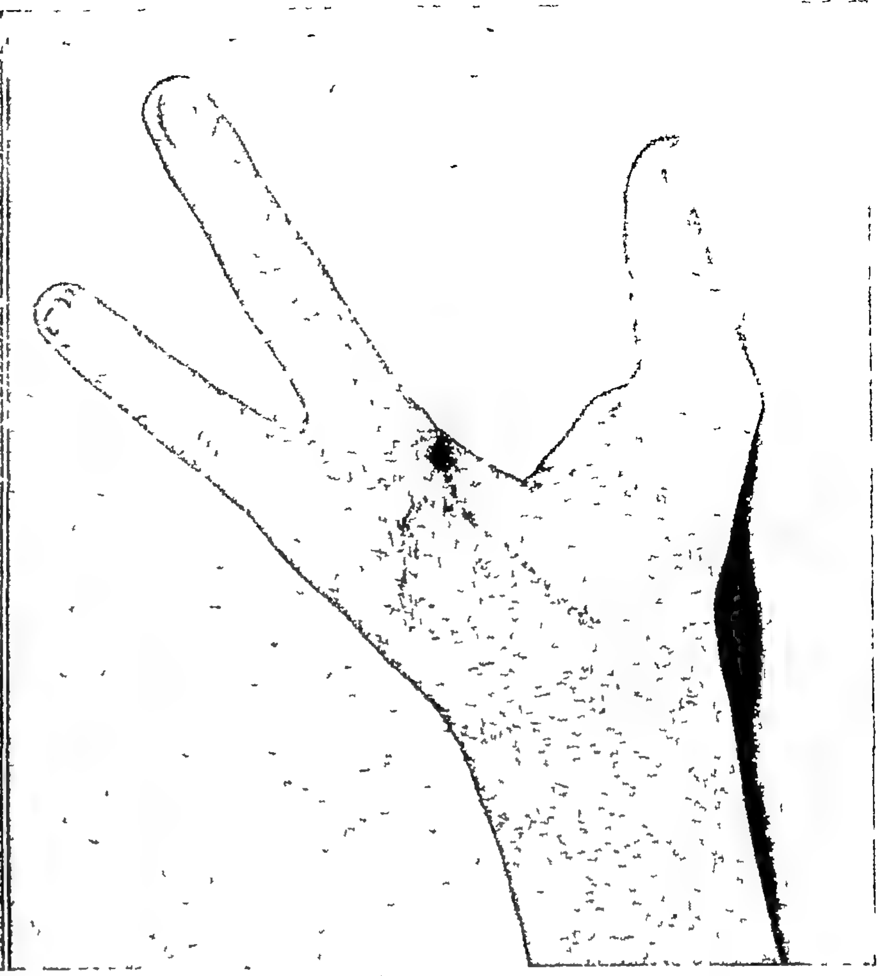

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Fig 194—Disarticulation of the thumb and little finger at the carpal-metacarpal joints, and the ring finger at the metacarpal-phalangeal joint Because of a posterior dislocation at the intercarpal and carpal metacarpal joints, this patient had a surprising amount of grasp between the fingers and the base of the hand (Walter Reed General Hospital Neg No 4349 2)

Fig 195—Disarticulation of the index and middle finger rays at the level of the carpus This hand had satisfactory pinch and hook between the thumb and remaining fingers, but grasp was poor due to the lack of a satisfactory palmar base and the absence of the two strongest fingers (Official U S Signal Corps Photo)

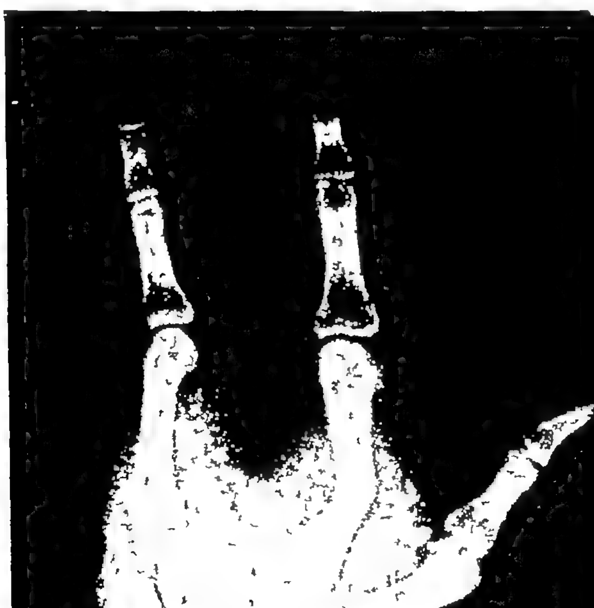

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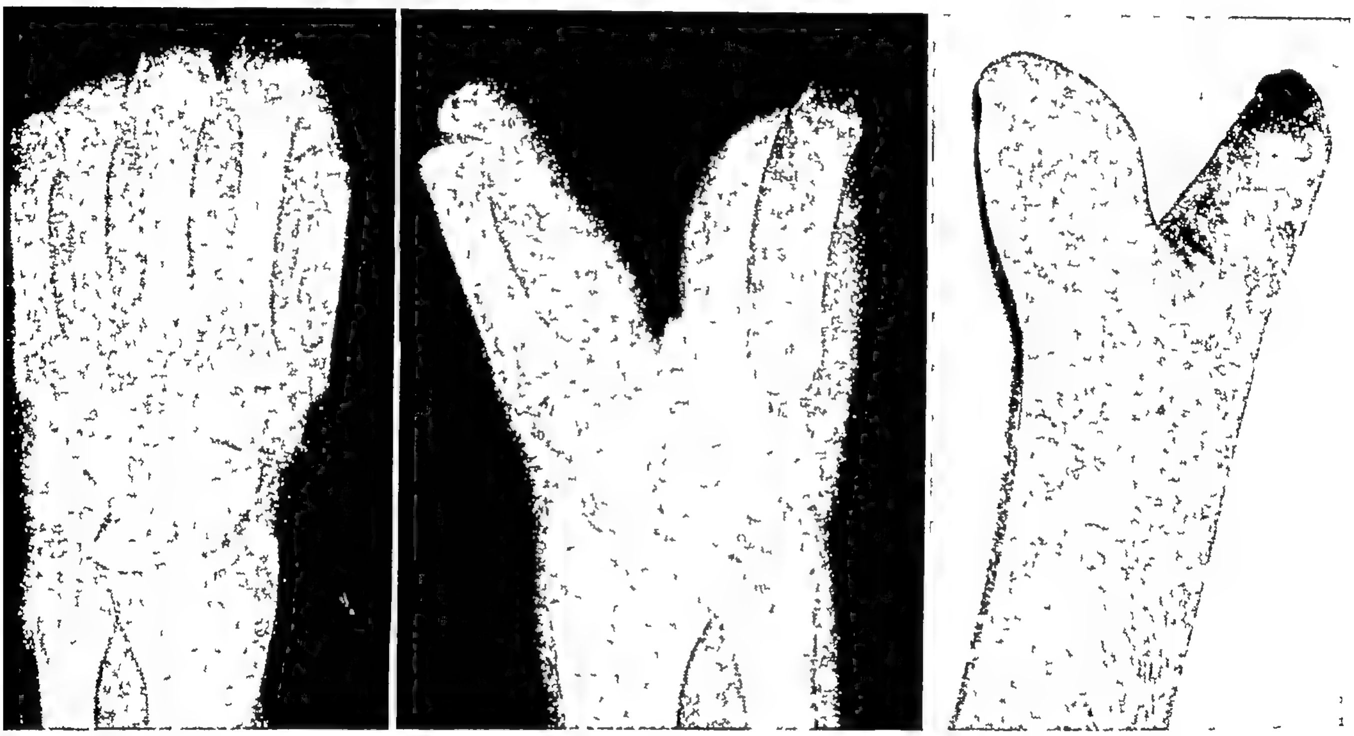
Fig 196—Amputation of the third and fourth metacarpals at their bases with old fracture of the shaft of the second metacarpal Grasp, pinch, and hook were satisfactory with the remaining fingers since the breadth of the palm was fairly well maintained It was a constant source of annoyance to this patient, however, to try and hold small objects in the palm of his hand since they would fall through the gap between the two fingers (Walter Reed General Hospital Neg No 4700 A1)

In amputation of all rays through the proximal metacarpus, the surgical procedure for repair consists of making a rounded bony contour covered with well-padded skin, preferably palmar in type From a prosthetic viewpoint, this level is awkward and difficult to fit The patient must be willing to have a prosthesis which measures an inch or two longer than the opposite arm to allow room for the mechanism When worn without a prosthesis, the stump itself is more useful than those where amputation is at a higher level This is due to its length and because flexion and extension of the wrist and pronation and supination of the forearm have been preserved The technique of this amputation is similar to that which will be described under the carpus, except that the flaps are slightly longer



198 199 200

Figs 198 200 —Formation of a bifid hand The fingers had been amputated at the level of the metacarpal phalangeal joints and the thumb through the base of the proximal phalanx The second and third metacarpals were resected together with the lesser multangular and the capitate bones Note the beveling of the neck of the fourth metacarpal to form a rounded contour at the end of the ulnar digit Note also how widely the digits can be spread for grasp (Courtesy of Dr R H Alldredge England General Hospital Neg Nos RC 103, RC 102, SA 360)

AMPUTATIONS ABOUT THE WRIST

Amputation at this level has been the subject of considerable discussion The crux of the argument is which is functionally superior, amputation about the wrist or severance through the forearm?

Amputation through the carpus or disarticulation of the wrist have two distinct advantages over amputation at a higher level First, pronation and supination are preserved, second, the prosthesis can be adapted to the stump without the cumbersome and uncomfortable above-elbow cuff In addition, amputation through the carpus retains flexion and extension which make the stump of considerable functional value without an artificial member On the other hand, there are two common objections, the difficulty in fitting a prosthesis, and the poor quality frequently attained in the stump itself

The first objection is based on the fact that the length of the stump leaves little room for the wrist mechanism required, and, as a consequence, the artificial hand or hook may extend below its normal fellow. This discrepancy, however, can be minimized by the skilled limb maker. I have had under my personal observation seventeen cases of wrist disarticulation and have found that difference in length between the normal hand and the wrist stump with an artificial hand was only three-fourths of an inch, taking as the site of measurement for both the point where the index finger touches the thumb. There was no discrepancy when the short hook was used. Obviously, amputation through the carpus would increase this difference by one-half to three-fourths of an inch. Such a disparity is so slight as to be scarcely apparent or objectionable and may in time be largely eliminated by future prosthetic developments. Another criticism sometimes expressed from the prosthetic viewpoint is that rotation is not transmitted to the artificial limb. This depends entirely upon the care with which the limb is constructed and is scarcely a valid protest. In the seventeen cases just mentioned, the range of pronation and supination with the prosthesis was about half that obtained by the stump alone. Even such partial transmission makes the function of the prosthesis at this level superior to that at the forearm, where no rotation is present.

As to the objection to the quality of the stump itself, this is based on the high incidence of stumps at this level with poor vascularization and impaired mobility. Such a resultant stump is due to errors in indication and faulty technique. In order for amputation to be indicated about the level of the wrist, the structures available must be such that the stump will fill the following three basic requirements.

1. It must be covered with palmar skin with a thick layer of subcutaneous fat and normal blood supply. If the thin avascular skin of the dorsum of the wrist is used, or the anterior surface of the wrist above the palm, a cold cyanotic stump, tender, painful, and subject to ulceration, will usually follow.

2. It must retain painless motion in the distal radioulnar joint. If this joint has been severely damaged by trauma or infection, or if its stability is impaired by loss of the triangular ligament, an arthritic condition may develop which will result in pain on pronation and supination, and will render the stump valueless.

3. It must be free from unpadded, projecting, bony prominences. If prominences are poorly protected, they will frequently become contused and abraded with the use of the prosthesis, and if the skin is drawn too tightly over the bony base, particularly in the region of the styloid processes in wrist disarticulation, the stump may become avascular.

When these three basic requirements can be met, that is, when a tough, well-padded, well-vascularized integument can be provided, and painless motion can be maintained, amputation about the wrist is functionally excellent both with and without a prosthesis. When they cannot be fulfilled, the result is most unsatisfactory. In short, amputations about the wrist are very like the little girl with the curl in the familiar nursery jingle, "when she was good she was very, very good, and when she was bad she was horrid." When, in all probability, it will be "horrid," the wrist level should be abandoned, and severance should be undertaken through the site of election in the forearm.

The selection of the bone level in amputation about the wrist demands some explanation. The site of choice is through the carpus at any level compatible with adequate skin covering, for the flexion and extension of that unit is invaluable when a prosthesis is not worn. If the carpus cannot be preserved, wrist disarticulation should be carried out at the level of the radiocarpal joint. The

technique of this procedure may be altered according to anatomic variations. If the distal end of the radius is unusually concave, a small amount of carpus may be retained to fill the depression; if the radial and ulnar styloids are exceptionally prominent, their distal points may be trimmed to effect a smooth contour. Care should be taken, however, to leave the expansion on the lateral aspect of the radius because of its value in maintaining the prosthesis, while special pains should be exerted in trimming the ulnar styloid to ensure that the triangular ligament is not disturbed. This structure is the stabilizer of the underlying radioulnar joint, and any procedure which destroys its integrity is unsatisfactory, for rotation of the forearm becomes markedly limited and pain may develop both on motion and on lateral pressure. The resection of the distal end of the ulna has been attempted to relieve this situation, but success has so infrequently attended this procedure that it cannot be recommended.

Amputation Through the Carpus

Amputation at this level is easily performed, for the radiocarpal joint is not invaded, and the carpal bones are simply rounded to a smooth contour and covered with palmar skin. The flaps are cut so that the suture line lies on the terminal end of the stump, just posterior to the level of the styloid processes.

OPERATIVE PLAN. Bone level at the most distal point in the carpus compatible with skin covering by a long palmar and short dorsal skin flap.

TECHNIQUE. Amputation through the carpus utilizes a long palmar and short dorsal flap in the length ratio of two to one. The anterior incision starts in the mid-portion of the anatomic snuff box, swings downward over the thenar eminence to the mid-palm, and then extends ulnarward to a point on the side of the hand just above the base of the fifth metacarpal. From this point, the posterior limb of the incision follows a distal arc over the bases of the metacarpal bones to join the palmar incision at its starting point. The flaps will vary in length with the carpal bone level. The skin flaps are dissected upward for a short distance to expose the underlying structures. The long flexors and extensors of the fingers are identified, drawn down, and cut short enough to allow retraction of their proximal ends upward into the forearm. The flexors and extensors of the wrist are reflected upward over the bone level, to be reattached later to the end of the bone at the most distal convenient point in line with their normal insertions.

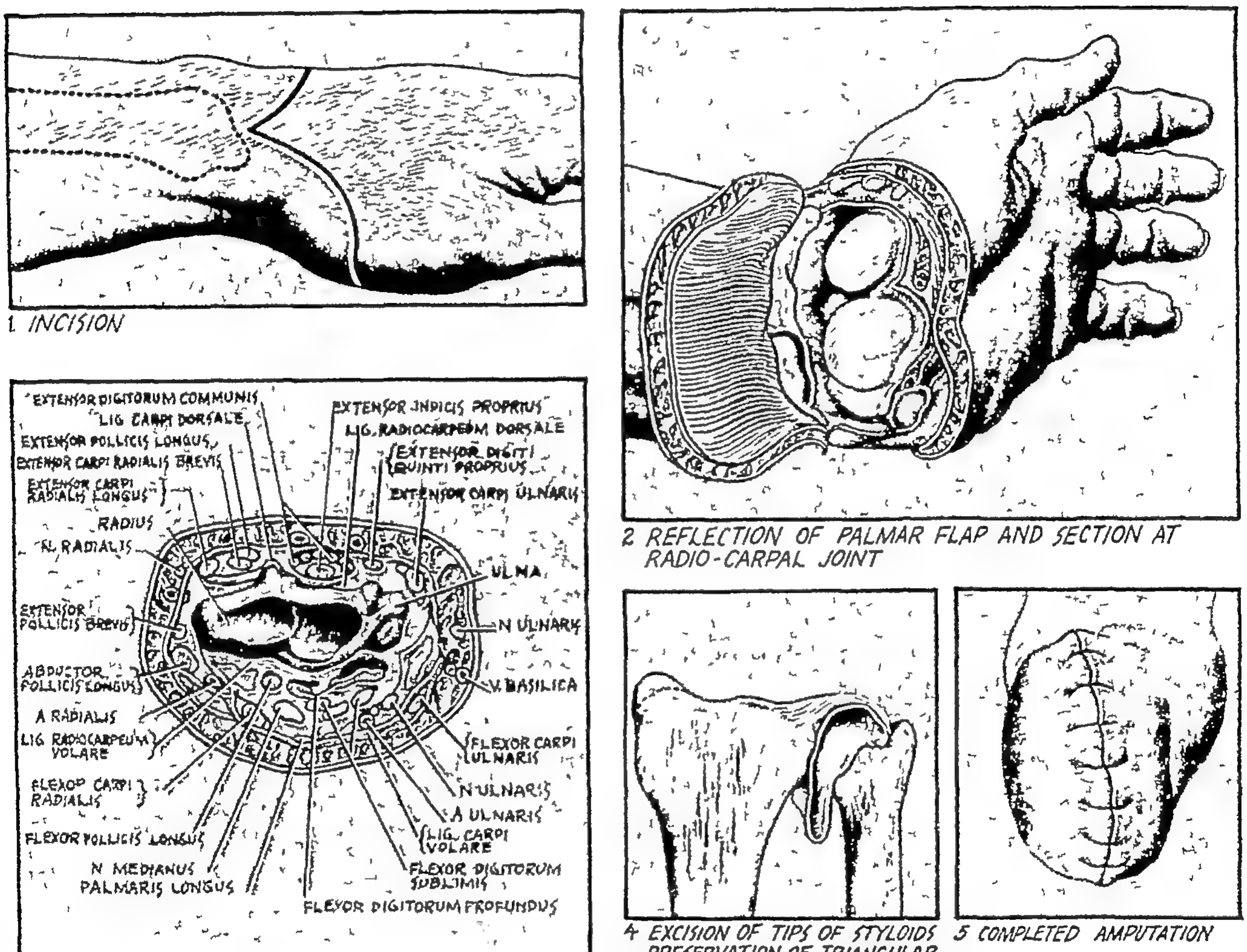
The bone level in carpal amputation is the most distal point at which bone may be covered by satisfactory skin. When this is determined, the carpus is either sectioned or disarticulated through the intercarpal or carpometacarpal joints. A smooth, rounded contour is obtained by removing all projecting bony eminences. The major vessels are isolated, doubly ligated, and allowed to fall in their beds. The median and ulnar nerves are isolated, drawn down, sectioned, and allowed to retract upward. The fine filaments of the radial nerve on the dorsal-radial aspect of the stump are treated in a similar manner. The tourniquet is released and hemostasis is secured. The palmar flap is approximated to the dorsal flap and any redundancy is trimmed. The skin should be sutured under minimal tension so that there will be no interference with the flexion or extension of the wrist. The wound is dressed with dry gauze. A drain may be used if hemostasis is not complete. Elastic bandage compression is applied.

Disarticulation of the Wrist

The ideal stump in disarticulation of the wrist is soft, well padded, nontender, and roughly oval in shape. The scar is terminal, mobile, and linear, and lies just behind the level of the styloid processes of the radius and ulna so that the anterior flap covers the anterior two-thirds of the distal end of the stump

The skin on the anterior aspect of the wrist will retract readily, and the thick palmar skin will thus be drawn upward so that it will lie over the anterior lip of the radius and protect it in much the same way that it does when the normal wrist joint is flexed. Although the tips of the styloids should be removed, the distal ends of the radius and ulna should retain their normal configuration in order that the flare may be grasped by the prosthesis.

OPERATIVE PLAN. Disarticulation is performed through the radiocarpal joint, care being taken to leave the distal radioulnar joint undisturbed. Integument is supplied by a long anterior flap of palmar skin, and a short dorsal flap.



1. INCISION

2. REFLECTION OF PALMAR FLAP AND SECTION AT RADIO-CARPAL JOINT

3. CROSS SECTION

4. EXCISION OF TIPS OF STYLOIDS PRESERVATION OF TRIANGULAR LIGAMENT AND UNDERLYING JOINT SPACE

5. COMPLETED AMPUTATION

Fig. 201.—Disarticulation of the wrist

TECHNIQUE. The skin incision starts over the lateral aspect of the wrist joint in the mid-point of the anatomic snuff box, one-half inch below the styloid process of the radius (to allow for skin retraction). From there it passes palmarward to the level of the carpometacarpal joint of the thumb, crosses the palm to the fifth metacarpal-hamate joint, and thence swings upward to a point one-half inch below the ulnar styloid. From here, the dorsal incision proceeds across the back of the wrist in a gentle distal arc and joins the starting point of the palmar incision. The skin flaps are reflected upward to expose the radiocarpal joint, and the radial and ulnar arteries are sectioned and doubly ligated. It should be noted here that it is much simpler to isolate the ulnar artery before section because of its tendency to retract upward into the forearm. The median,

ulnar, and the terminal superficial branches of the radial nerve are isolated, pulled gently downward, sectioned transversely, and allowed to retract upward above the terminal radial flare The remainder of the dissection is carried out on the radial side of the wrist, with the hand in strong ulnar deviation The ligaments and tendons are divided at their highest level As the ulna is approached, the triangular ligament and the underlying radioulnar joint are carefully preserved When this dissection is complete, the wrist and hand are freed and discarded The distal ends of the radius and ulna need no special treatment The articular cartilage need not be removed The skin flaps are placed over the ends of the bone, and the styloid processes are palpated If they are unduly prominent, they can be gently rounded The tourniquet is released and complete hemostasis is secured The skin flaps are approximated and any final trimming of the flaps is carried out They are then brought together without tension and held in position by interrupted skin sutures Dry gauze dressings are applied and fixed by gentle elastic bandage compression

Postoperatively the arm is elevated for several days The sutures are removed on the tenth to twelfth day Bandaging of the forearm is continued until shrinkage is maximal

In the past, wrist disarticulation has been carried out by a number of methods These include the simple circular incision at the level of the wrist joint, the simple circular incision at the level of the carpometacarpal joint, the use of medial and lateral flaps, the use of the thenar flap, the hypothenar flap, the dorsal elliptical flap, and the palmar elliptical flap The simple circular incision at the level of the radiocarpal joint does not provide satisfactory skin to cover the stump end When skin from this area is used, the bony contours of the wrist are unusually prominent, the skin is tight and thin, and a cold, painful, avascular stump usually follows The simple circular incision at the level of the carpometacarpal articulation provides skin with adequate nutrition, but it results in a bulky, unsightly stump which is not readily fitted with a prosthesis Medial and lateral flaps are not recommended because of the resulting anteroposterior scar in the midline of the stump A thenar flap may occasionally be used when there is loss of the tissues on the ulnar side of the hand The radial portion of the incision starts in the midline at the base of the thenar eminence and has its apex at the first metacarpophalangeal joint whence it passes dorsally and proximally to end at the first metacarpal-greater-multangular joint The ulnar half of the incision is at the level of the pisiform bone When the flap is swung ulnarward and fixed, it usually forms a satisfactory, well-padded stump The hypothenar flap is the exact counterpart of the thenar flap, with its apex at the level of the proximal digital crease of the little finger, and it is indicated where there is a loss of the thenar integument The dorsal elliptical flap provides very poor skin as stump covering, while the palmar elliptical flap provides satisfactory skin with good circulation, but both are undesirable because of their bulk In summary, it may be said that the procedure employing a long anterior and short posterior flap and covering the end of the stump with palmar skin is the only routinely satisfactory method Although the others are of historical interest, they are not to be recommended

AMPUTATION THROUGH THE LOWER THIRD OF THE FOREARM

Amputation in the lower third of the forearm is poor from the standpoint of the stump because the skin is thin and avascular, and the underlying soft tissues are largely tendinous and fascial Healing is relatively poor The stump is frequently cold, tender, and cyanotic, and secondary breakdown is common Even in the occasional case where the skin is satisfactory, the stump

is not particularly adaptable to the prosthesis because of the poor muscular padding about the radius and ulna, and it is of no functional value in itself, as is that created by amputation through the carpus

From the prosthetic standpoint, also, amputation at this level is unsatisfactory, for it does not incorporate the valuable pronation and supination and the elimination of harness that are found in wrist disarticulation, nor is the long lever arm presented any more powerful in activating the prosthesis than is the shorter one which results from amputation at the junction of the middle and lower thirds of the forearm Its length is, in fact, a disadvantage, for it requires additional length and bulk in the lower end of the prosthesis, which is cosmetically undesirable The recently developed forearm prostheses incorporating pronation and supination are not adaptable at this level

AMPUTATION AT THE JUNCTION OF THE MIDDLE AND LOWER THIRDS OF THE FOREARM

Amputation at the junction of the middle and lower thirds of the forearm produces the ideal below-elbow stump from the viewpoint of function and appearance The skin is tough, the circulation is good, and adequate subcutaneous covering for the bone end is present, there is more muscle and less tendon for lateral bone padding than at the more distal level It provides a strong lever arm which is long enough to control the prosthesis and to allow the upper edge of the forearm cuff to rest two to three inches below the anterior aspect of the elbow, thus making possible full flexion without pinching in the antecubital region

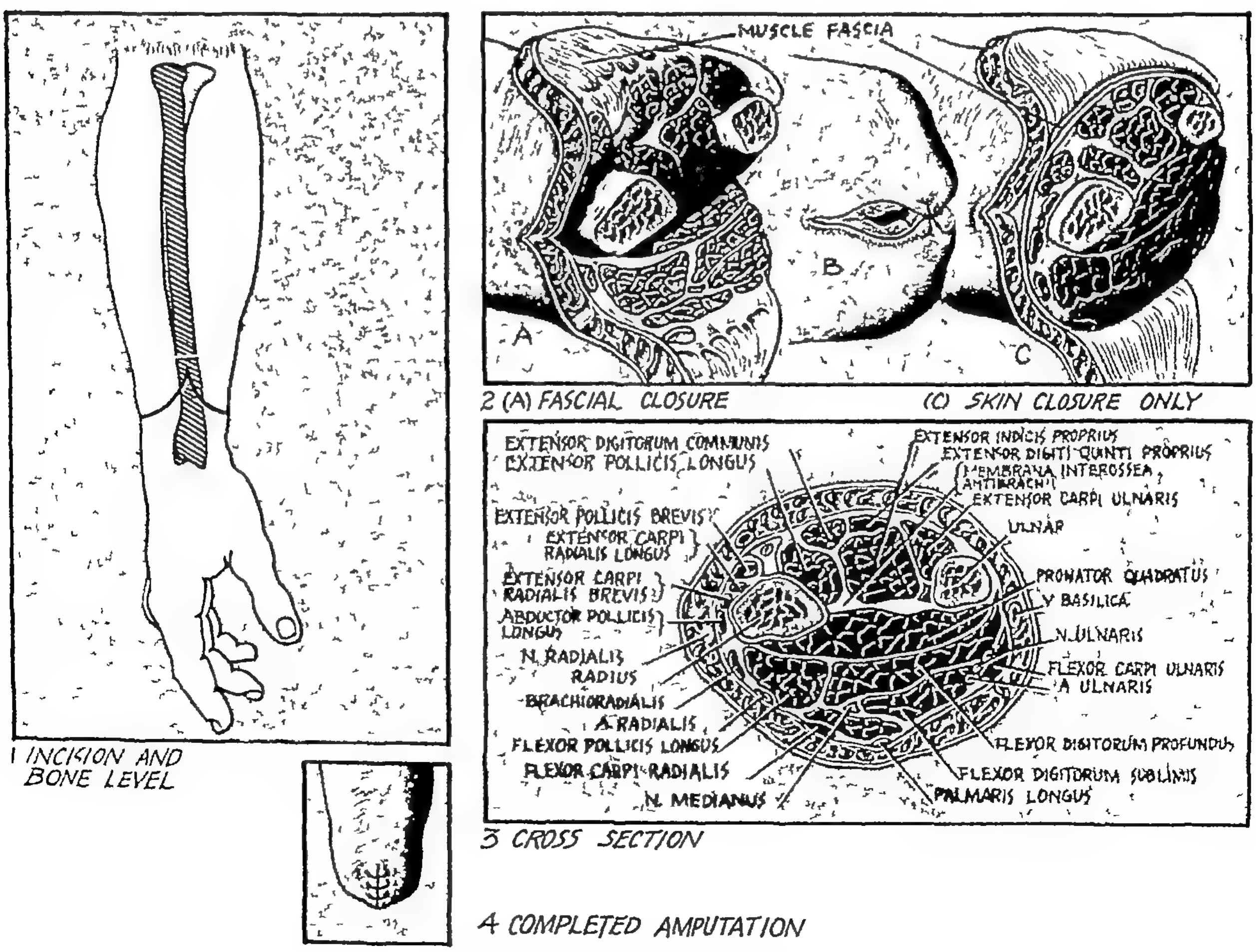


Fig 202—Amputation of the forearm

The forearm stump has a tendency to fall into moderate pronation Rotation exercises should be instituted early to counteract this and to avoid a pronation contracture Occasionally a synostosis will occur between the distal ends of the radius and ulna, precluding rotation Although this is no obstacle in the use of the standard forearm prosthesis, it will minimize the advantage of the newer type which incorporates rotation, and which is now becoming commercially available

OPERATIVE PLAN Bone level at the junction of the middle and lower thirds of the forearm, two to three inches above the radial styloid Anterior and posterior flaps of equal length forming a terminal suture line The flaps may be formed of skin alone, of skin and fascia, or of skin, fascia, and muscle I prefer the method which includes in the flaps a layer of skin and a layer of fascia Techniques for all three methods will be presented

POSITION An arm board at the side of the operating table is used, and the arm is placed in moderate flexion at the elbow with the forearm midway between pronation and supination

TECHNIQUE

1 **Incision** Skin flaps are cut so that their combined lengths are equal to the diameter of the arm at the bone level The incision starts at the midpoint on the radial side of the forearm at the bone level, and swings convexly downward across the dorsum of the forearm and then upward to the midpoint on the ulnar side of the forearm at the bone level The anterior incision is made in a similar manner The flaps thus formed are rounded and slightly tapering

2 **Treatment of soft tissues**

a *When skin alone is used for covering over the end of the bone,* the fascia and muscle are cut one-fourth to one-half inch below the intended bone level so that they will fall flush with it after retraction When this is done, the bone end will not be prominent beneath the skin and the muscles will be well grouped around the sides Usually this method provides a satisfactory stump, but occasionally further muscle retraction will occur, and a few months after final closure, the bone end will be prominent beneath the skin and the stump will be subject to trauma both with and without a prosthesis

b *When skin and fascia are used to cover the bone end,* the fascial flaps are cut in the same pattern as the skin flaps They are then reflected upward and the muscles are sectioned so that they will fall at the intended bone level The fascial flaps are brought over the end of the bone and sutured by means of interrupted 00 plain catgut sutures The fascia thus forms an excellent padding over the bone end and acts as an anchor for the cut muscles, preventing their further retraction and ensuring their grouping about the sides of the bone

c *When skin and myofascial flaps are used to cover the bone end,* care should be taken that no large redundant muscle masses are employed, because of their tendency to become boggy and edematous The layer of muscle investing the bone end should not be more than one-fourth of an inch in thickness Of the several methods by which the myofascial flap can be formed, that described by Kirk is the most satisfactory In accordance with that technique, after the skin flaps are reflected upward, the flexor sublimis and its investing fascia are incised to form a flap similar to the overlying skin flap but of a length equal to the diameter of the forearm at the bone level The remaining muscles of the forearm are sectioned transversely so that they will retract to the intended bone end When closure is effected, the myofascial flap is brought dorsally

across the wound and sutured to the extensor muscles and the dorsal fascia This method affords a layer of desirable thickness and is to be preferred to the frequently used technique which employs the flexor and extensor muscles and fixes them with a terminal suture line over the bone end, for this latter procedure adds excessive bulk to the end of the stump

3 **Osteotomy** The treatment of the bone requires no special technique The periosteum is sectioned one-eighth inch above the intended bone level and stripped downward The bone is cut at right angles to the long axis of the arm as it is held in the mid-position, and the bones are then smoothed with a file or rasp The medial aspect of the cortex of the ulna and the lateral aspect of the cortex of the radius may be beveled This refinement improves the contour of the end of the bone somewhat and is especially desirable where the skin is thin and adequate circumferential muscle covering cannot be supplied All bone dust is washed away from the wound with normal saline, and the bone end checked to see that it is perfectly smooth and that no tags of periosteum remain

4 **Treatment of the nerves and vessels** The median, ulnar, and radial nerves are isolated, drawn gently downward into the wound, and sectioned with a sharp knife Strong traction and rough handling of the nerves are scrupulously avoided since the tendency to neuromata formation and phantom limb in the upper extremity is very great After section, the nerve should fall back in its bed and be well protected by muscle The major blood vessels require no special attention other than careful isolation and double ligation with plain catgut The tourniquet is removed and meticulous care is given to hemostasis

5 **Closure** If fascial or myofascial flaps are used, they are fixed as described above The skin flaps are then approximated, carefully tailored, and sewn by interrupted skin sutures under tension equivalent to that normally found in this area A drain is placed between the first and second sutures, extending downward beneath the fascial layer It should never be inserted directly at the angle, because in such a position it frequently delays healing The wound is dressed with dry gauze and swathed in two or three layers of sheet wadding An elastic bandage extending upward as far as the elbow joint is applied under mild tension

FOREARM AMPUTATION ABOVE THE IDEAL LEVEL

Amputation through the forearm, even above the ideal level, is far superior to severance through the upper arm because it retains the elbow joint The artificial arm worn by the above-elbow amputee incorporates a mechanical elbow which cannot be locked voluntarily but must be set at the desired degree of flexion or extension by a ratchet which must be operated by the normal hand It is evident that such a means of control is awkward and frequently inconvenient For this reason it is exceedingly important, whenever possible, to retain the elbow joint even though it may not have total motion and even though the humerus may not be normal Since the upper extremity is nonweight-bearing, the corset of the prosthesis will usually stabilize the humerus sufficiently if it is defective in any way No reconstructive measures should be undertaken which would in any degree impair the function of the elbow through permanent immobilization

As a general rule, the shorter the forearm stump, the closer the upper rim of the socket of the prosthesis must come to the elbow joint and the greater will be the impediment to flexion The highest level at which amputation can be carried out and still provide a stump which can be contained within the prosthetic socket and effectively activate the artificial limb is one and one-half inches below the biceps insertion In order to obtain this measurement, the elbow is

flexed at right angles against resistance in order that the biceps tendon will stand out The length is then taken from that structure to the end of the stump If it is possible for amputation to be carried out distal to that point, the technique employed is the same as that described for severance at the ideal site, with the exception of a few variations in the treatment of the muscles In order to avoid bulk, muscle wedging may be necessary upon occasion, and if the myofascial flap technique is used, the muscle thus employed must be reduced to a thickness of not more than one-fourth inch If amputation must be performed at the one and one-half inch level or immediately distal to it, functional stump length may be increased by section of the biceps tendon or actual stump lengthening by bone graft The former is the method of choice in all cases where it is applicable, stump lengthening being reserved for those few cases where section of the biceps alone will not be adequate, and where the operation itself will not limit the motion of the elbow joint

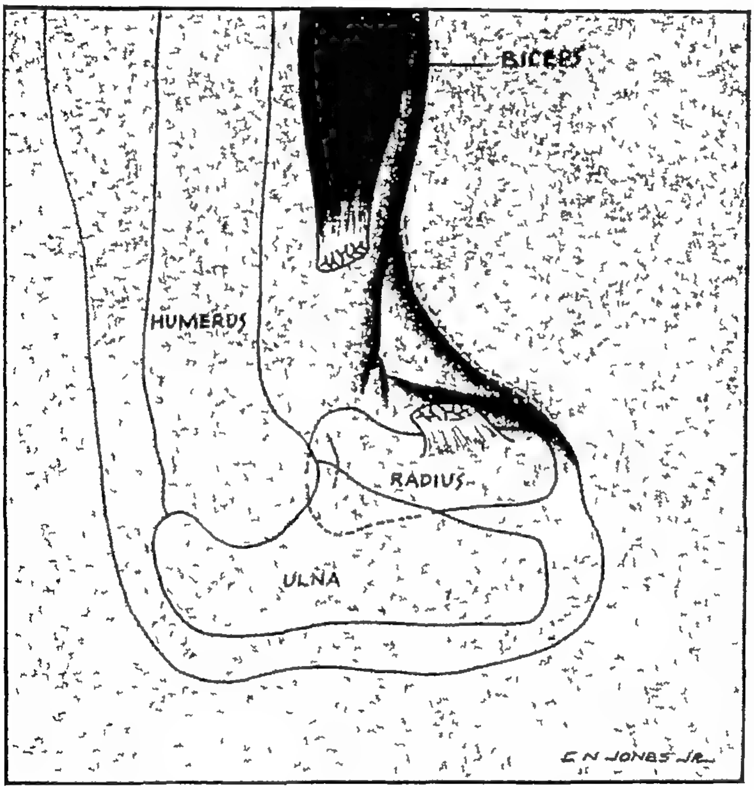


Fig 203—Section of the biceps tendon in short below elbow amputation to facilitate the use of the prosthesis

1 **Biceps section in short forearm stumps** (Blair and Morris) This procedure is preferably carried out at the time of final plastic closure of a short forearm stump, but may, of course, be done at a later date in an amputation which has already undergone final repair In the former instance, the radial attachment of the biceps is exposed by undermining the anterior flap, while, in the latter, it is revealed by a transverse incision The incision is made one inch above the flexion crease of the elbow in order that the surgical scar will not be subject to pressure from the socket of the prosthesis Following exposure, the tendon is sectioned at its insertion and pulled downward with an Ochsner forceps, and its distal one inch is resected The remainder of the tendon is allowed to retract proximally so that it will not become reattached in the antecubital region

2 **Lengthening of the short forearm stump by bone graft** The bony architecture and the amount and distribution of the skin is so protean in short below-elbow stumps that no standardization of technique can be presented Suffice it to say for the purpose of this discussion that lengthening is accomplished through bone graft, that this procedure must not interfere with future elbow function, and that the grafted bone must be well padded by skin and underlying soft tissues

AMPUTATIONS ABOUT THE ELBOW AND THROUGH THE HUMERUS

Whether to perform disarticulation of the elbow or transcondylar amputation, or to carry out severance of the arm through the shaft of the humerus has long been a moot question The success of any amputation within this area is gauged by the adaptability of the resultant stump to an artificial arm with a functional elbow joint

As was noted previously, the standard upper arm prosthesis is composed of a tubular socket, which fits about the upper arm stump, and a forearm piece, and these are hinged at the elbow joint At that point there is a mechanical device by which the arm may be fixed in various degrees of flexion This mechanism usually occupies two inches longitudinally within the upper arm piece It is obvious that the stump must be sufficiently long to be grasped by the socket, but that it must on the other hand be short enough to allow room for the mechanism if the artificial elbow joint is not to fall below that of the normal arm Experience has proved that the ideal stump length to meet these requirements is achieved by amputation through the supracondylar area of the humerus In addition, severance at this level is relatively easy to perform from the surgical standpoint since there are no flaring condyles requiring large amounts of skin and subcutaneous tissue for covering, and the bone end needs only to be rounded and smoothed The stump created at this level is gently tapering and is easily fitted within the upper arm socket

There are some who contend that the pipelike humeral shaft with its mobile overlying soft tissues provides little rotary fixation and that for this reason disarticulation of the elbow or transcondylar amputation, which affords a knobby stump end for the prosthetic socket to grasp, is preferable Such a stump, however, does not allow sufficient room for the joint mechanism and must be fitted with a specially constructed artificial member which utilizes a molded leather socket and lateral hinges in place of the conventional elbow block This hinge to some extent minimizes the disparity between the level of the normal elbow joint and that of the artificial one The fact remains, however, that the construction and adjustment of such a prosthesis is difficult and should not be undertaken by any but an exceptionally skilled limb maker

In my opinion, the limitation of rotation of the stump within the socket does not compensate for the awkwardness of the overlong lever arm and joint, the difficulty in adaptation of a prosthesis, and the presence of the bony prominences so apt to form pressure points within the socket and so difficult to provide with adequate integument

Disarticulation of the Elbow Joint

Operative Plan The formation of skin flaps of equal length, the division of the bone at the level of the ulnarhumeral and radiohumeral joints, and the provision of adequate covering of muscular tissue to eliminate the irregularity of the distal articular surface

TECHNIQUE

1 **Incision** The posterior incision starts at the level of the medial epicondyle, curves gently downward to a point on the dorsal surface one inch below the olecranon tip, and thence upward to the lateral epicondyle The anterior incision arises at that point, swings downward immediately below the insertion of the biceps tendon, and thence upward to join the posterior incision at its point of origin When necessary, in order to utilize available skin, an oblique incision may be employed, and a long anterior or long posterior extension formed

2 **Treatment of the soft tissues, vessels, and nerves** The skin is undermined in the interval between the superficial and deep fascia, and dissected upward to the level of the epicondyles The arm is placed in the position of slight flexion and full supination, and the deep dissection is begun on the medial side The lacertus fibrosus is divided, and a finger is inserted beneath the flexor tendons which arise from the medial epicondyle These are isolated and divided at the level of the joint line The neurovascular bundle lying against the medial aspect of the biceps tendon is now in plain view The brachial artery is isolated, clamped, sectioned and doubly ligated, the median nerve is dissected free, pulled gently downward, and cut in such a manner that it will retract one inch above the joint line The ulnar nerve is isolated as it lies in the ulnar groove and sectioned above the epicondyle The flexor tendons are then freed from the forearm, the biceps tendon is dissected free from its radial insertion, the brachialis tendon is severed from its insertion immediately below the coronoid process of the ulna The dissection proceeds to the lateral aspect of the arm, and the radial nerve is identified in the groove between the brachialis and brachioradialis, isolated, drawn down, and sectioned The extensor muscles arising from the lateral epicondyle are sectioned approximately two and one half inches below the joint line and reflected upward The posterior fascia and the triceps tendon are incised near the olecranon

3 **Disarticulation and closure** The anterior capsule is severed to complete the disarticulation and the forearm is removed The triceps tendon is drawn forward over the end of the joint, and sutured to the brachialis and biceps tendon The extensor muscles attached to the lateral epicondyle are trimmed to form a thin muscle flap which is swung toward the medial epicondyle covering all bony prominences and all exposed tendon This flap is sutured to the cut flexor muscles Additional periosteal sutures are usually desirable to aid in the fixation of these muscle groups Hemostasis is secured, and the anterior and posterior skin flaps are approximated Closure is effected by interrupted skin suture, and a drain is instilled in the wound A dry dressing is applied with elastic compression bandage

Transcondylar Amputation

OPERATIVE PLAN Section of the bone through the condyles, terminal fixation of the flexor and extensor muscles over the bone end, and formation of anterior and posterior flaps of equal length

TECHNIQUE Anterior and posterior skin flaps are formed by incisions starting at either epicondyle The medial muscle mass is dissected free from the epicondyle The median nerve and brachial artery are isolated, the median nerve is cut and allowed to retract one inch above the stump end, the brachial artery is sectioned and doubly ligated, the biceps tendon is severed at its insertion to the radius, and the brachialis tendon is severed at its insertion to the ulna The radial nerve is isolated in the groove between the brachioradialis and the biceps, drawn down, and cut short The lateral muscle group is sectioned

at the level of the condyle The posterior fascia and triceps tendon are severed at the joint line The anterior capsular structures are divided A saw line is selected through the condyle, and transverse section of the bone is carried out The anterior and posterior lips of the transected bone are gently rounded, and all bony prominences removed from the medial and lateral aspects of the bone end The flexor and extensor muscle groups are sutured to one another, hemostasis is secured, and the skin flaps are fixed to one another by interrupted suture

Amputation Through the Supracondylar Region of the Humerus

OPERATIVE PLAN Section of the bone through the supracondylar level and formation of a single long flap of triceps tendon and anterior and posterior skin flaps of equal length

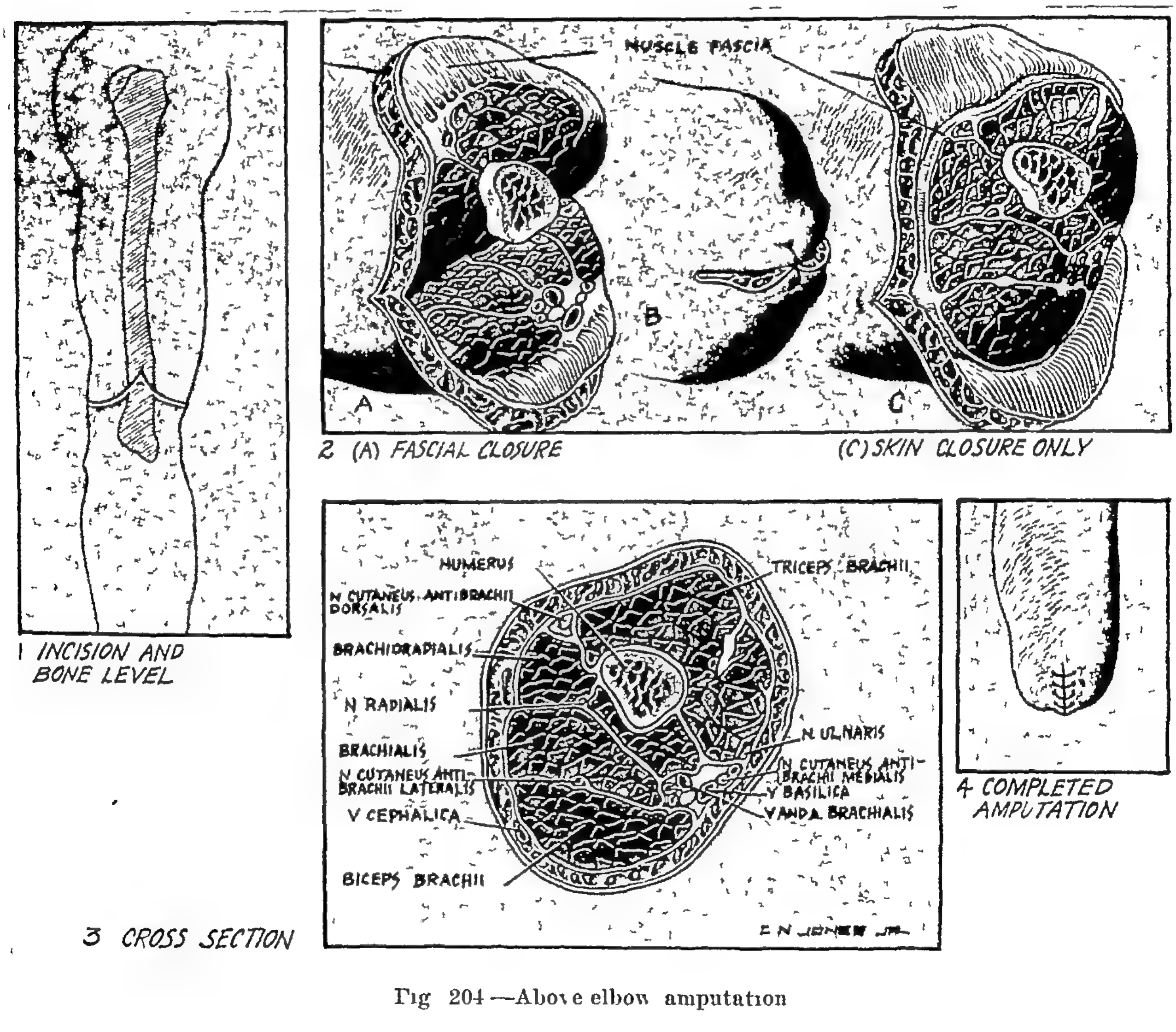


Fig 204—Above elbow amputation

TECHNIQUE

1 **Incision** The incision starts at the supracondylar level and follows a distal arc across the anterior surface from a starting point on the mid-lateral portion of the arm to a like point on the median aspect of the arm A similar flap is cut on the dorsal surface The length of each flap is equal to one-half the anteroposterior diameter of the arm at the intended bone level

2 **Treatment of the soft tissues** The muscles of the anterior aspect of the arm are sectioned approximately one-half to three-fourths of an inch distal

to the saw line so that they will fall flush with it after retraction The broad flat expansion of the triceps tendon is cut at the level of its insertion to the olecranon

3 **Osteotomy** The periosteum is incised circumferentially about one-eighth of an inch proximal to the intended bone level The bone is sawed transversely, and its rough surfaces are smoothed with a file Bone dust is washed away with normal saline

4 **Care of the nerves and vessels** The brachial artery is isolated, doubly ligated, and sectioned The median, ulnar, radial, and cutaneous nerves are isolated, drawn gently down, and sectioned to fall above the bone end The tourniquet is released and hemostasis secured

5 **Closure** The triceps tendon is brought forward over the end of the bone and sutured to the fascia of the brachialis and biceps muscles The skin flaps are approximated and fixed at the terminal midline by interrupted sutures

An alternate method used by many is the covering of the bone end by skin alone, all muscles being cut transversely to fall at the saw line Although this method must frequently be employed of necessity in the plastic repair of open amputations, it is not recommended as the procedure of choice, for it affords no anchor for the cut posterior-anterior muscle groups and they may retract further, leaving the bone end protruding and unprotected

AMPUTATION OF THE ARM ABOVE THE SUPRACONDYLAR AREA

The highest level at which amputation can be performed above the supracondylar area and still provide a functional stump is two inches below the axillary fold (Measurement is taken from this point since it is the most proximal site at which the upper rim of the prosthetic socket can be fitted) It is obvious that a stump of lesser length than this could not be grasped well by the prosthesis and in abduction and forward and backward flexion would tend to fall out of the socket Since the preservation of all possible length is the first consideration in this area, the site of election is the most distal point commensurate with adequate covering

Operative Plan The formation of a single long myofascial flap to ensure lateral and terminal protection for the bone, and the creation of anterior and posterior skin flaps of equal length This plan may be altered when the triceps muscle and its investing fascia, and skin from the designated areas are not available The use of fascia and skin, or even skin alone, is admissible if such a modification is necessary to achieve a stump of functional length In such instances any available tissues may be used

Technique The skin flaps are of equal length, each being slightly longer than one-half the anteroposterior diameter of the arm at the bone level The anterior incision starts at the mid-point on the lateral aspect of the arm, passes downward to reach a maximum length in the midline of the anterior surface of the stump, and then swings upward to a mid-point on the medial surface The posterior flap is cut in a similar manner The anterior muscles are sectioned to fall at the bone level The triceps and its overlying fascia are sectioned about one to one and a half inches below the bone level The major vessels are isolated, tied by double ligature, severed, and the major nerves are drawn down, sectioned, and allowed to fall back above the end of the stump The triceps muscle is then beveled to form a thin layer and is brought over the bone end, and sutured to the biceps and the other anterior muscles The skin flaps are approximated and fixed by interrupted sutures In amputations in which the deltoid muscle is sectioned, the insertion should be reattached to the bone end in order that abduction may be retained

NEOARTHROSIS OF THE SHAFT OF THE HUMERUS FOR AMPUTATIONS ABOUT THE ELBOW JOINT (Gillis)

The creation of a joint in the shaft of the humerus and a forearm segment has been carried out by Gillis on the basis of the following indications (1) in above-elbow amputations, where at least four inches of the shaft of the humerus still remain below the insertion of the deltoid muscle, (2) in through-elbow amputations, (3) in very short below-elbow amputations which cannot be fitted with a below-elbow prosthesis, (4) in cases of congenital absence of the forearm This interesting alternative to the cineplastic operation has as its objective the conservation and utilization of the muscular power of the flexors and extensors of the forearm and the formation of a new joint and a forearmlike segment about four inches in length

OPERATIVE PLAN The formation of a new joint with a range of 90 degrees or more requires the wide excision of bone at the site of neoarthrosis, the encouragement of nonunion, and the minimization of callus formation This is accomplished through the extraperiosteal excision of one and a half to two inches of humeral shaft, the fulguration of the bone ends by electrocautery, the use of sulfanilamide to inhibit phosphatase activity, and the immobilization of the arm in a straight plaster cast for a period of three weeks

TECHNIQUE Through a three and one-half inch posterior incision at the level selected for the formation of the neoarthrosis, the triceps muscle is exposed and split longitudinally to expose the underlying humeral shaft This incision is used to minimize the damage to the flexor muscles, the triceps muscle being less important since extension is aided by gravity The humerus is now exposed extraperiosteally and a section measuring one and a half to two inches in length is removed The ends of the bone are now fulgurated with the electrocautery, hemostasis is secured, and sulfanilamide is instilled into the wound The wound is closed in the usual manner with interrupted sutures, dry dressings are applied, and the stump is placed in a straight plaster cast The cast is removed three weeks postoperatively and faradism and graduated exercises are initiated with a view to promoting flexion of the stump The stump is wrapped with a figure-of-eight crepe bandage on maximum tension to reduce the edema and stretch the triceps muscle Following the return of the tissues to normal and the development of adequate muscle power, the prosthesis is fitted It is to be noted here that the prosthesis protects the new joint from lateral instability

AMPUTATIONS ABOUT THE SHOULDER

Amputations about the shoulder include (1) severance through the surgical neck of the humerus and (2) disarticulation of the shoulder at the scapulohumeral joint Since the site of election is above the level of the axillary fold, a functional prosthesis cannot be worn, nor is the stump itself of any functional value Due consideration, however, should be given the cosmetic factor Of the two, disarticulation is the more unsightly, because the acromion process projects laterally and there is a depression immediately beneath it formed by the hollow of the glenoid cavity of the scapula This distortion of line may be somewhat minimized by padding the glenoid cavity well with the surrounding muscle Amputation through the surgical neck is less deforming, for the glenoid cavity is filled by the head of the humerus, and the shoulder presents a more normal appearance If this procedure is carried out above the attachment of the pectoralis major, the short rotators tend to force the remaining bone into flexion and abduction, while if performed below the pectoralis attachment, the humerus will

hug the thoracic wall. Following either of these procedures, the use of the prosthesis is impractical since the stump furnishes no motivating power to it, the limb is heavy, and the harness is cumbersome and uncomfortable. It, therefore, serves only for cosmesis and is usually soon discarded in favor of the empty coat sleeve.

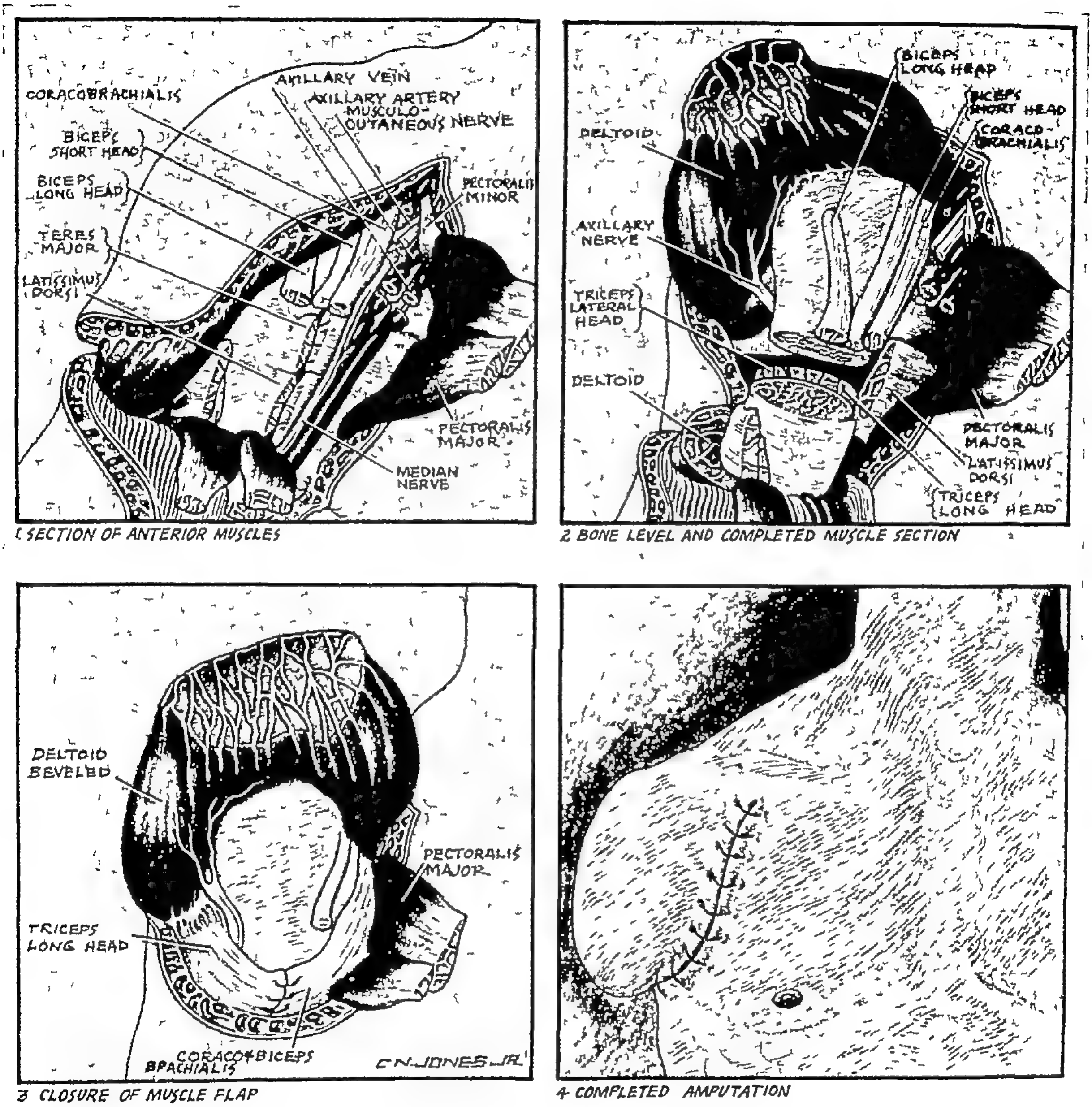


Fig 205.—Amputation through the surgical neck of the humerus

Amputation Through the Surgical Neck of the Humerus

Operative Plan. A large lateral flap of deltoid muscle and its overlying skin are reflected upward to reveal the underlying structures. The bone is sectioned at the level of the surgical neck, in order to leave a bony mass to fill the glenoid cavity, and its sides are padded by additional muscle.

Position. The patient is placed in the dorsal decubitus position with a sandbag placed well beneath the scapula in such a manner that the thorax will

form an angle of about 45 degrees with the operating table The sandbag should be placed far enough medially so that there will be ample room for operative preparation and draping The arm is placed in slight abduction

TECHNIQUE

1 **Incision** The anterior incision begins at the level of the coracoid process, which lies approximately two fingerbreadths below the clavicle in the deltopectoral groove It follows a course slightly medial to the anterior border of the deltoid muscle as it proceeds downward to the insertion of that structure It then crosses the lateral aspect of the arm and swings upward to the axillary fold, passing just behind the posterior border of the deltoid muscle The arm is then widely abducted, and a second incision is made across the axilla to join the first incision at the level of the anterior and posterior axillary folds

2 **Treatment of the soft tissues** The pectoralis major muscle is identified and sectioned near its insertion It is then reflected upward so that the groove between the pectoralis minor and coracobrachialis muscle may be deepened by section of the fascia along the coracobrachialis muscle to expose the neurovascular bundle The axillary artery and vein are sectioned just below the pectoralis minor muscle, and the median, ulnar, radial, and musculocutaneous nerves are isolated, drawn down, and sectioned so that they fall beneath the pectoralis minor muscle The deltoid muscle is sectioned about one-half inch above its insertion to the humerus, and the deltoid flap with its overlying skin reflected upward The teres major and latissimus dorsi muscles are sectioned near their origin at the bicipital groove of the humerus Biceps, triceps, and coracobrachialis muscles are cut at a point three-fourths of an inch distal to the saw line

3 **Bone section** The humerus is transected at the level of the humeral neck and the bone ends are smoothed Bone dust is washed away from the wound with normal saline

4 **Closure** The coracobrachialis and long head of the biceps muscle are sutured over the cut surface of the humerus The pectoralis major is swung laterally and sutured to the inferior pole of the bone The deltoid flap is now trimmed, and the distal surface of the deltoid muscle is dropped downward to be fixed to the myotendinous mass beneath the cut end of the humerus The skin flaps are tailored for accurate approximation and fixed to the humerus with interrupted skin sutures

A drain is placed at the inferior pole of the wound Dry dressings are applied, and a pressure dressing fixed with an elastic type of adhesive is used Drains are removed in from forty-eight to seventy-two hours Stitches are taken out between the tenth and twelfth day

Disarticulation of the Shoulder

OPERATIVE PLAN A long lateral flap consisting of skin and deltoid muscle is reflected upward like the hinged lid of a teapot, to afford exposure and removal of the underlying bone and soft tissues When resection has been completed, the lid is allowed to fall downward to cover the glenoid cavity

TECHNIQUE

1 The **position** and the skin **incision** are exactly the same as those used for amputation through the surgical neck

2 **The exposure and section of the neurovascular bundle** The pectoralis major muscle is identified sectioned near its insertion to the humerus, and

Fig 206 —Disarticulation of the shoulder

reflected medially to expose the entire axilla The groove between the pectoralis minor and coracobrachialis is identified, and the loose axillary fascia is divided at a point near the coracobrachialis to expose the underlying neurovascular bundle (Care should be taken to avoid the space between the short head of the biceps and the bone) The axillary artery and vein are clamped, sectioned, and doubly ligated with heavy plain catgut and allowed to retract upward beneath the pectoralis minor muscle The thoracoacromial artery, which arises just proximal to the pectoralis minor, is ligated if it can be found The median, ulnar, radial, and musculocutaneous nerves are drawn down, sectioned, and allowed to fall upward beneath the pectoralis minor muscles also

3 **Section of the soft tissues** The coracobrachialis and the short head of the biceps are sectioned near their coracoid insertions The deltoid muscle is divided at a point one inch above its insertion and freed from its bony and soft tissue attachments It is then reflected upward to expose the capsule of the shoulder joint The arm is placed in extreme internal rotation, and the posterior capsule of the shoulder joint and the short rotator muscles (supraspinatus, infraspinatus, and teres minor) are sectioned near the humerus The arm is next placed in extreme external rotation, and the dissection carried forward through the capsule on the anterior aspect of the joint The attachment of the subscapularis muscle is sectioned at this time, and the teres major and the triceps muscle are sectioned near their insertions The inferior capsule is divided to complete the severance of the limb

4 **Wound closure** When complete hemostasis has been secured, the pectoralis major, teres major, and subscapularis muscles are reflected toward the glenoid cavity to fill it as much as possible, and are then sutured in position The deltoid flap is brought downward to cover the area of the glenoid cavity, and the muscle is fixed in this position with several stitches The skin of the flap is then approximated to the axillary skin and closed in the usual manner with interrupted sutures If sufficient skin is available in the deltoid flap, the axillary limb of the incision may now be extended downward below the hair line of the axilla to eliminate this unsightly tuft on the lateral chest wall Care should be taken not to excise too much axillary skin until a test fit has been made to ensure adequate skin closure

A drain is inserted in the posterior-inferior angle of the wound in the most dependent portion A compression dressing is applied and fixed with an elastic type of adhesive The drain is removed in from forty-eight to seventy-two hours Stitches are removed on the tenth or twelfth day A protective dressing may be retained for several weeks until there is no longer tenderness over the shoulder when clothing is worn

FOREQUARTER AMPUTATION

The forequarter amputation, sometimes called shoulder girdle amputation or interscapular-thoracic amputation, is the surgical removal of the upper extremity in the interval between the scapula and the thoracic wall It is one of the most deforming of all amputations, for the removal of the shoulder girdle leaves a sharply sloping contour between the neck and the lateral thoracic wall This may be disguised somewhat by the use of a shoulder cap which gives the appearance of normalcy and allows the amputee to wear clothing of standard cut Although an artificial arm can be worn at this level, it has no functional value and is exceedingly cumbersome The only indication for this radical procedure is malignancy of the upper end of the humerus, scapula, or axilla It is obvious that mutilating surgery such as this may be attended by consider-

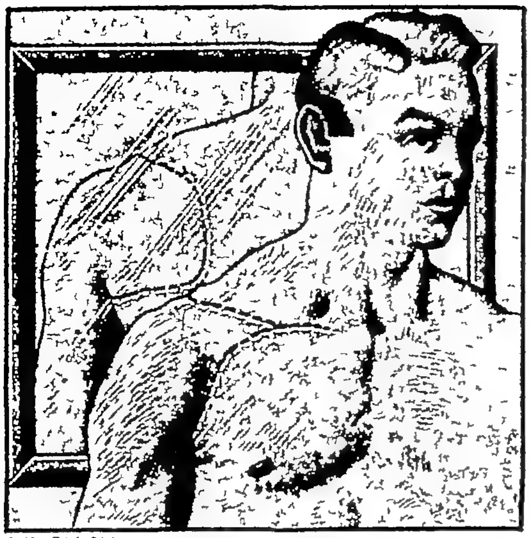
able shock, and it is incumbent upon the surgeon to be prepared for the administration of blood, plasma, and intravenous fluid during operation. When malignancy is present, a standard pattern of operation cannot always be followed, but must be modified in accordance with the location and extent of the malignant process. The variations are so numerous that it is only practical to describe a routine procedure which may be altered at the will of the surgeon.

Operative Plan. A racquet incision is used with its queue overlying the clavicle, and its elliptical portion passing over and around the shoulder joint. Following exposure, the shoulder girdle is removed by section of the clavicle and the muscles attached to the scapula, and by severance of the vessels and nerves passing downward into the arm. The upper and lower parts of the racquet incision will fall together after the removal of the bone and soft tissues.

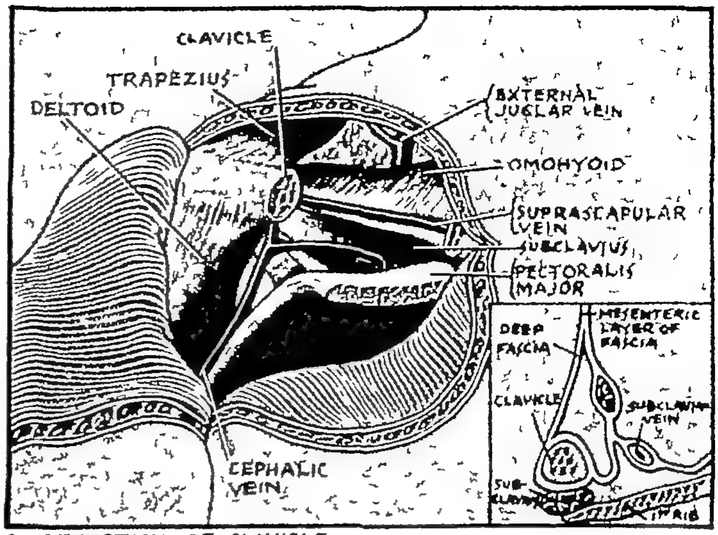
Technique

1. **Incision.** The incision starts at a point two fingerbreadths lateral to the sternoclavicular articulation at a point corresponding to the lateral border of the sternocleidomastoid insertion. It follows the anterior aspect of the clavicle laterally through its entire length, crosses the acromioclavicular joint and passes over the top of the shoulder to the spine of the scapula. At this point, the arm is flexed over the chest to rotate the scapula forward and outward so that its bony contour is outlined in greater relief. The posterior aspect of the upper incision now follows downward over the spine of the scapula to its vertebral border which it follows distally to the angle of the scapula. The lower portion of the ellipse starts in the middle third of the clavicle, passes downward in the groove between the deltoid and pectoral muscles to the anterior axillary fold. The arm is abducted and the incision is continued across the axilla at the level of the junction of the skin of the arm with the axillary skin. As the incision passes the posterior axillary fold, it continues medially across the back to join the upper incision at the angle of the scapula.

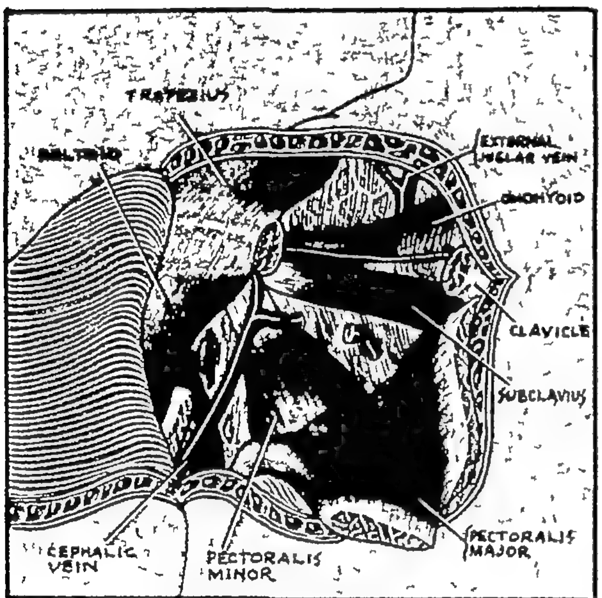
2. **Treatment of the anterior soft tissues, resection of the clavicle, and care of the neurovascular bundle.** The head is bent toward the normal side in order that the sternocleidomastoid muscle may be better outlined, and the pectoralis major muscle is severed from its clavicular insertion, the dissection starts at the lateral border of the insertion and proceeds close to bone to the lateral border of the sternocleidomastoid muscle. The pectoral muscle is then reflected downward and medially. If further exposure is needed, the humeral insertion of the pectoralis major may be divided. The upper border of the clavicle is exposed by sectioning the superficial layer of the deep fascia along the upper border of the clavicle as far medially as the sternocleidomastoid muscle. Further dissection beneath the clavicle is carried out by means of the finger or a blunt curved dissector. The external jugular vein which emerges just above the clavicle at the lateral border of the sternocleidomastoid may be sectioned and ligated if it is in the way. The clavicle is divided by a Gigli saw at the lateral border of the sternocleidomastoid muscle. It is not desirable to section the clavicle more medially because of the danger of injuring the subclavian vein which hugs its medial inch. The clavicle is sectioned at or near the acromioclavicular joint, and the freed portion is removed. If the humeral insertion of the pectoralis major muscle has not already been sectioned, this is now done. That whole muscle may now be reflected downward and the entire shoulder girdle may be retracted outward and downward so that the axillary and subclavian region is in full view. The axillary fascia is sectioned, the pectoralis minor is severed from its coracoid insertion, and



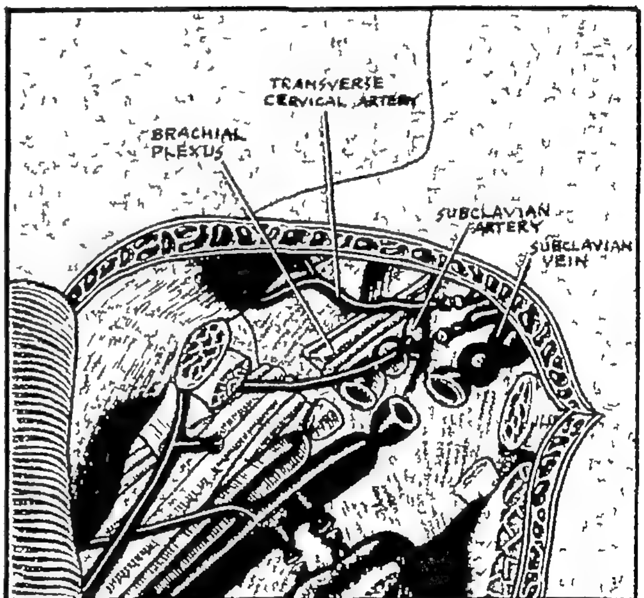
1 INCISION



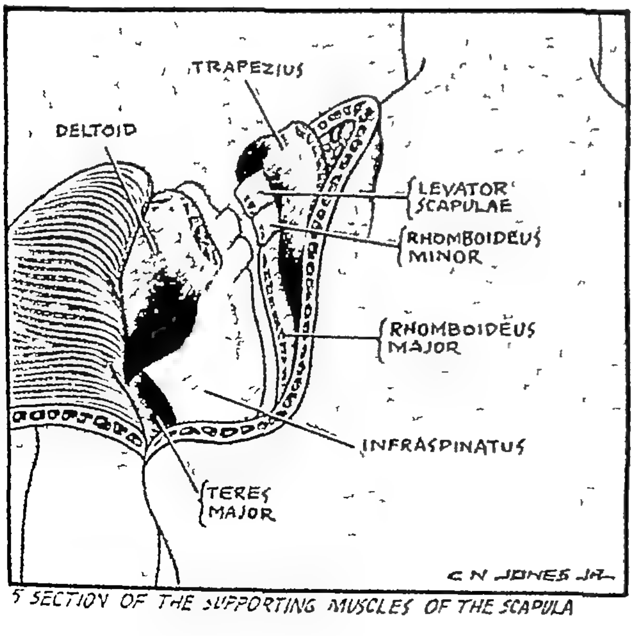
2 RESECTION OF CLAVICLE



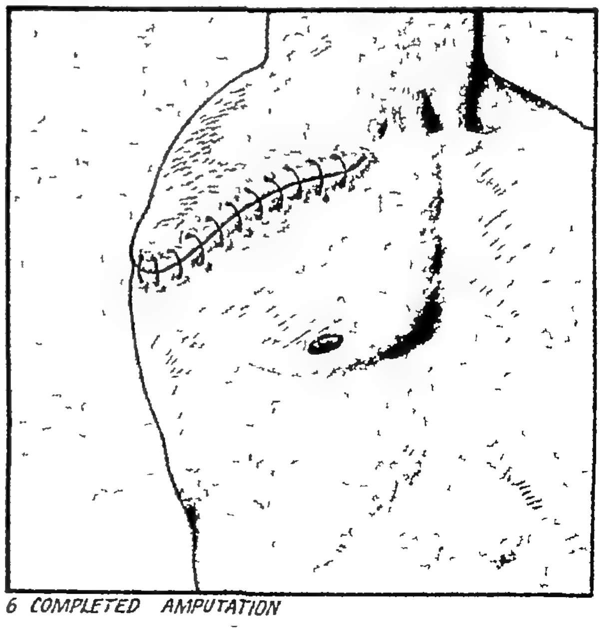
3 LIFTING THE PECTORAL LID



4 SECTION OF VESSELS AND NERVES AFTER INCISION THRU AXILLARY FASCIA, INSERTION OF PECTORALIS MINOR COSTO-CORACOID MEMBRANE AND SUBCLAVIUS



5 SECTION OF THE SUPPORTING MUSCLES OF THE SCAPULA



6 COMPLETED AMPUTATION

Fig 207 —Forequarter amputation

these muscles may gain an excursion of two to three centimeters of active powerful motion It is always desirable to have both a flexor and extensor motor that active opening and closing of the hand may be carried out, but in some cases where the skin over the extensor region has been damaged or the muscles are inadequate, a flexor motor alone may be used In this case, the flexor activation is used to open the hand, and a spring mechanism in the artificial hand itself is used for closure As the upper third of the forearm is approached, the muscle bellies disappear, and the location of the motors in the forearm muscles must be abandoned If the elbow remains normal, however, it should be preserved, for a good cineplastic stump can be achieved by retaining that joint for its flexion and extension action, and placing a cineplastic motor in the biceps muscle for the activation of the artificial hand Because of the length of the stump resulting from this measure, the biceps tendon is afforded maximal excursion, and the motor can be placed at the most distal extreme of the muscle belly, both of which factors make for greater power In the ideal case of this type, the excursion will be as much as six to seven centimeters, and the power as great as 25 to 30 pounds **In the upper arm** cineplastic amputation at the ideal level, the biceps muscle belly is used anteriorly, and the triceps posteriorly In the ideal case the biceps excursion will be four to five centimeters, and the triceps action between two and two and one-half centimeters Just proximal to the ideal level, the biceps muscle may frequently still be used for power activation, although its excursion becomes materially less, the triceps is rarely used for this purpose since it is usually of little functional value as far as power is concerned but a motor may be created within it to be used merely as a retention mechanism for the artificial limb so that loops to the opposite shoulder will not have to be used to maintain the prosthesis In the very short above-elbow amputation stump, the pectoral muscle may be used most satisfactorily

The formation of the muscle motor deserves special attention, for it must be able to withstand trauma, and must be so formed and so placed that it will transmit the maximum power When the most satisfactory motor site has been selected and a passage made through the muscle, the tube of skin is formed, passed through the tunnel in the muscle, and sutured to the skin along the longitudinal incision on the other side Thus a canal is created through which the ivory peg is to be placed In the construction of this canal, the following rules should be adhered to

1 The skin must be normal in type and free from scar

2 The canal should lie at right angles to the muscle fibers so that pull will be distributed properly

3 It should be short, since this enables the pull on the peg to be more readily balanced

4 The tube should be rotated 90 degrees at its base and retained in this position when its free end is fixed to the skin, so that the suture line will lie proximally and not be subject to the direct pressure of the peg as it is pulled by the cords

5 The canal should be sufficiently large to facilitate cleansing, and avoid breakdown and skin irritation Ideally it should admit the little finger if it is properly constructed

6 The canal must be placed as far distally as possible The strength of the motors is directly proportional to the muscle length since it is that factor which determines the amount of excursion, and it is the amount of excursion which in turn determines the amount of power In short, the greater the excursion, the greater the power

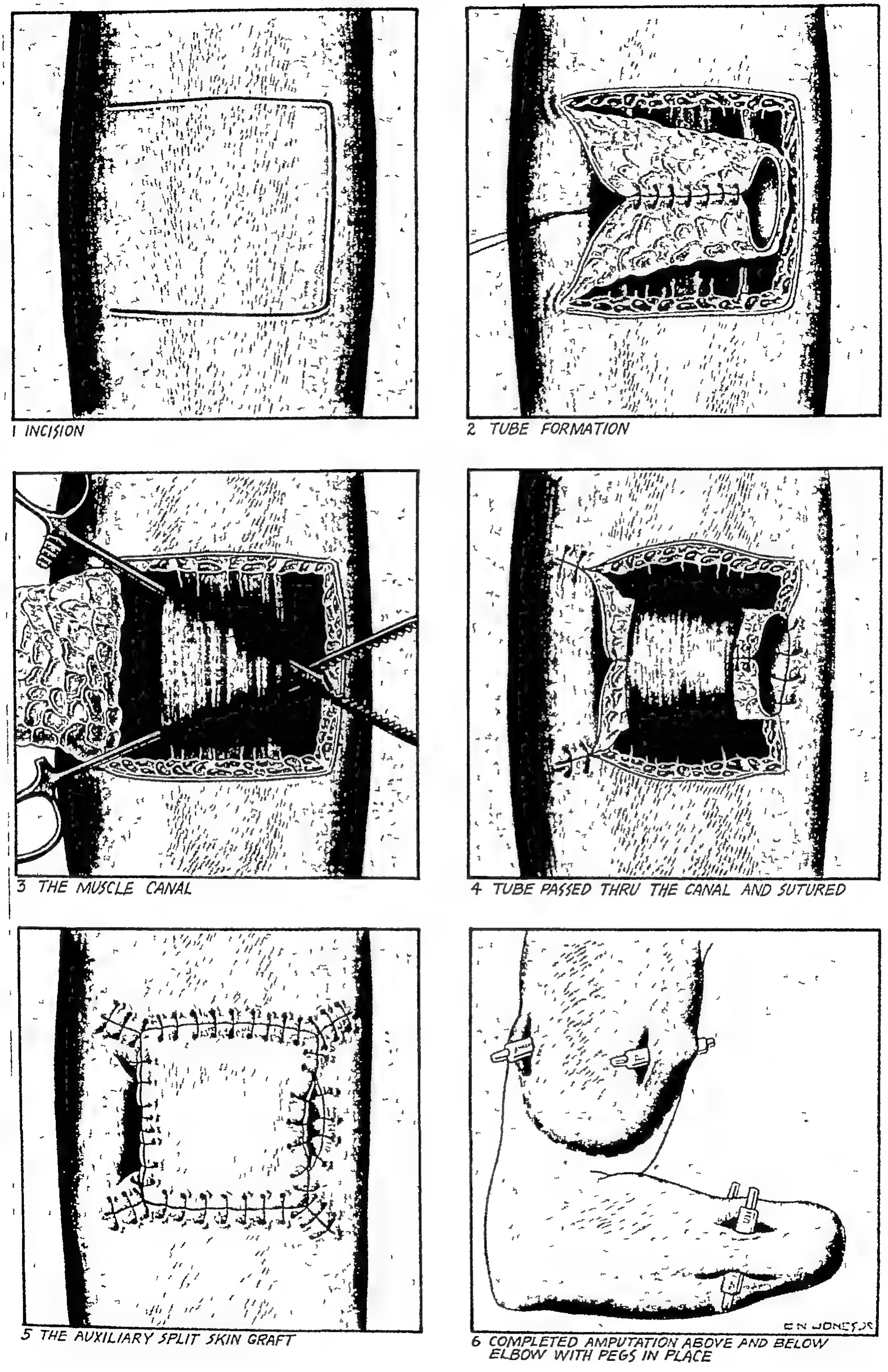


Fig 208 —Cineplastic amputation

7 The canal should not be placed so deeply within the muscle belly that it will lie close to bone, since the muscle would be fixed at that point and there would be little excursion to afford power, nor should it lie close to the skin since there would not then be adequate overlying muscle bulk to stabilize it There is some difference of opinion as to the exact depth within the muscle at which the canal should be placed Generally speaking, when the distal end of the muscle is left fixed to its attachment, the canal should be placed at a point representing one-third the distance from the surface to the bone This leaves two-thirds of the muscle body beneath the canal The pectoralis major, however, is routinely freed from its distal attachment, and in some instances the biceps is also, in order to allow greater excursion In all such cases, the canal should be placed so that two-thirds of the muscle body will overlie it

Technique

1 **Special preoperative steps** A donor site should be prepared, usually the lateral thigh or abdomen, for the split-thickness skin graft which will be required to cover the skin defect created by the formation of the tube If a general anesthetic is to be used, the patient should be requested to contract his flexor and extensor muscles actively, so that their course and location can be determined prior to surgery

2 **Incision** The skin incision is made in such a fashion that it will outline three sides of a square, each limb as well as the attached base being of equal length, and measuring not less than two inches The desired level for the motor is selected, and the incision is placed squarely over the muscle to be utilized The attached base of the tube may lie either medially or laterally depending upon the circulation in the area The incision crosses the surface at right angles to the muscle fibers, turns sharply and proceeds longitudinally the desired distance, then turns abruptly again to parallel the first horizontal limb It is deepened to the level of the deep fascia, and the flap is dissected backward over its base The full thickness of skin, the subcutaneous tissue and the fascia are used in order that the canal may have adequate circulation and be sturdy enough to withstand the trauma of the pull upon it Occasionally, in the obese patient, some subcutaneous fat will have to be trimmed away in order that the lumen of the tube may not be occluded It cannot be stressed too strongly that great care should be taken throughout in the handling of the tissues to be used in the tube, or canal, to ensure that the blood supply will remain unimpaired, and that a thin scar line will result It is advisable to use skin hooks and a very fine-toothed thumb forceps when manipulating the skin

3 **Formation of the tube** The two free corners of the skin flap are approximated in such a manner that the skin is inverted and the subcutaneous fat lies on the outside of the tube being formed These corners are fixed by a single silk suture which is left long to facilitate further handling A similar silk suture is then used to bring the skin at the other ends of the horizontal incisions together near the base of the flap The two long silk sutures are then grasped and drawn gently in opposite directions so that the horizontal edges of the skin flap are approximated, these edges are sewn with 000 plain catgut in the subcuticular tissues, silk is not used because of the difficulty in removing it once the tube is placed within the muscle tunnel Absolute hemostasis is assured within the flap before the next step is undertaken

4 **Formation of the muscle canal** The muscle is now grasped between the thumb and index fingers and pierced transversely at right angles to the muscle fibers The small hole thus made through the muscle is enlarged by the

index finger, or preferably by a blunt nosed, tapering dilator, if such an instrument is available When the tunnel is expanded so that it is one and one-fourth inches in diameter throughout, it is ready to receive the skin canal

5 **Passage of the skin canal through the muscle tunnel** The tunnel is held widely open and the skin canal is drawn through it by means of the long silk suture at its free end The surgeon should be assured that it lies at absolute right angles to the muscle fibers and that the tunnel is sufficiently large to avoid any pressure on the canal which might collapse it The canal is then rotated 90 degrees so that its suture line will face proximally, and its free end is fixed to the skin along the longitudinal incision by interrupted suture The angles at either end of the base of the flap are closed for a short distance, care being taken not to create tension on the wound

6 **Closure** A three-fourths thickness split skin graft of appropriate size is taken from the donor site and fixed over the exposed muscle to close the skin defect The graft may be held in position by interrupted sutures of silk or stainless steel, or by covering the whole with a piece of plain gauze fixed to the surrounding skin by skin glue

Postoperative dressing and aftercare The tube itself is dressed within with several layers of fairly dry petrolatum jelly or scarlet red gauze The wound is dressed with dry gauze, and the extremity is fixed with a plaster splint Care is taken to ensure that there is no undue degree of compression over the wound or adjacent skin which might interfere with the blood supply The stitches are removed on the eighth postoperative day, and the wound and canal are cleaned thoroughly Following removal of the splint and dressing, meticulous care is used in daily dressings of the tube and wound After the wound has been thoroughly healed, a peg is placed through the canal and exercises are started for the purpose of strengthening the muscles and accustoming the skin of the canal to the use of the peg

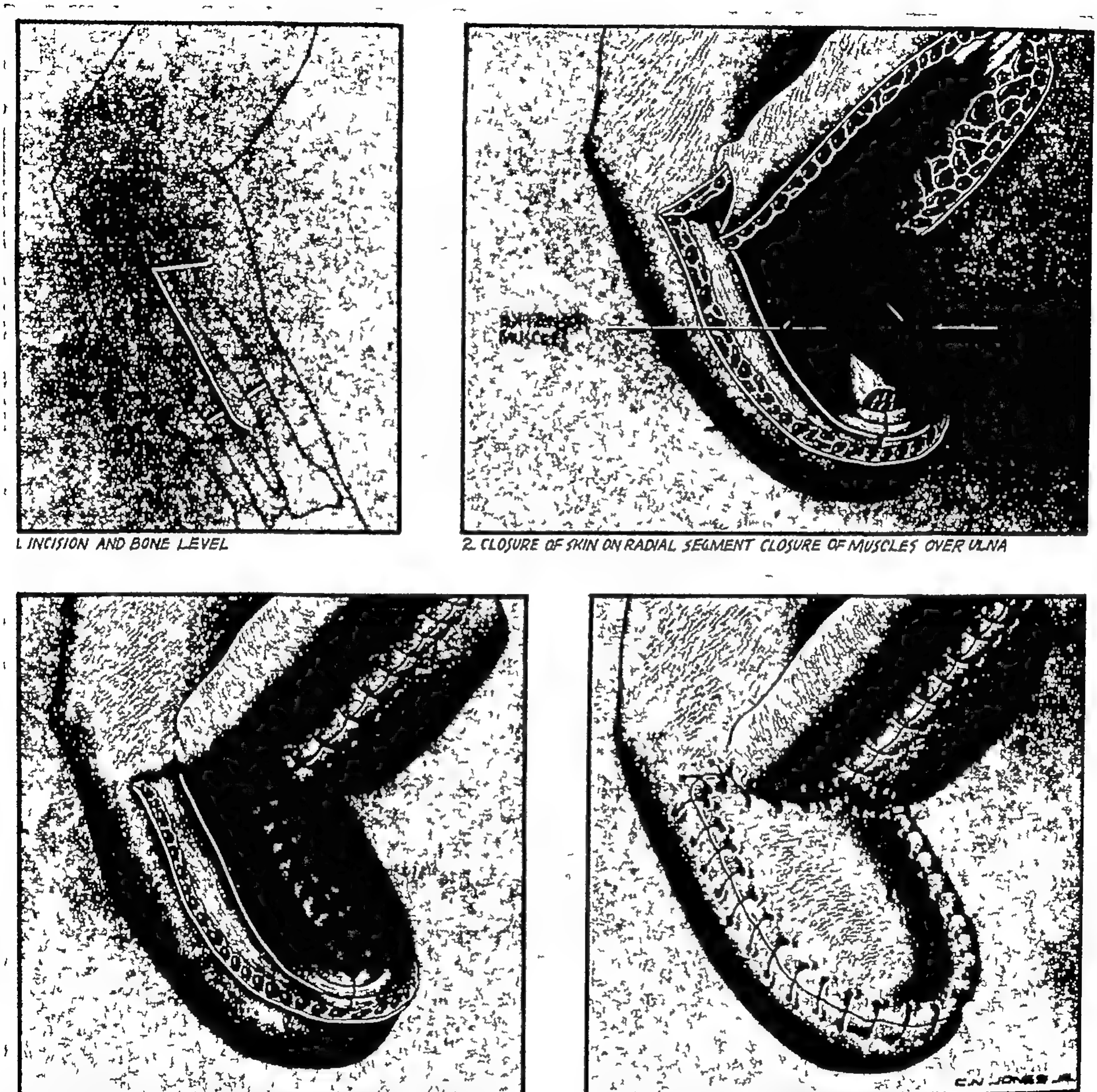
The Krunkenberg Operation

The Krunkenberg operation phalangizes the forearm stump by dividing it into a radial and an ulnar ray These two elements are formed by splitting the stump longitudinally at the interosseous membrane, widely separating the bone ends, and closing the skin defect between them by plastic methods Since muscle power is preserved for both the radial and the ulnar digit, a crude pinching mechanism is formed, the salient feature of which is the preservation of tactile sensation This makes the procedure of inestimable value to the bilateral blind amputee in whom neither site nor touch is present if prostheses are worn, a help to the bilateral amputee upon whom cineplasty has been performed in the other forearm stump for it allows him to place the pegs in the muscle canals and attach the apparatus of the artificial arm, and of occasional value to the unilateral forearm amputee Because of the unsightliness of the stump, the operation has never gained popularity in this country Although a prosthesis has been devised to disguise the appearance, this destroys the cardinal feature of the stump a functional pinching mechanism possessing sensation

Operative Plan This is a secondary operation on a forearm stump with a bone level at the junction of the middle and lower thirds of the radius and ulna in which these two bones are separated in the interosseous space, muscles are preserved for power and padding, and each element is covered by skin the radius by a local skin flap, and the exposed surface of the ulna by skin graft The ulna is motivated by the triceps which extends it, and the ulnar portion of the flexor sublimus which opposes it to the radius The radius utilizes the flexor

carpi radialis and the radial half of the flexor sublimis for apposition to the ulna, and the remaining extensors for opening the cleft

POSITION The extremity is placed on an arm board at the side of the operating table with the forearm midway between pronation and supination, and the elbow flexed to 90 degrees



1 INCISION AND BONE LEVEL

2 CLOSURE OF SKIN ON RADIAL SEGMENT CLOSURE OF MUSCLES OVER ULNA

3 COMPLETED SKIN CLOSURE OF RADIAL SEGMENT, COMPLETED MUSCLE CLOSURE OF ULNAR SEGMENT

4 COMPLETED AMPUTATION

Fig 209—Krunkenberg amputation

TECHNIQUE

1 **Incision** The incision is planned to form a skin flap which will invest the entire radial element after the development of the cleft between the two bones It starts three and one-half inches below the olecranon tip and proceeds distally along the radial border of the ulna, passes over the end of the stump, and thence proximally along the opposite side of the stump to a point coinciding with the origin of the incision At the upper end of the

incision on either side, a short radial incision about one inch in length is placed with a slight distal obliquity. The skin flaps thus created are reflected radially to the level of the bone to expose the underlying soft tissues covering the interosseous space.

2. **The formation of the cleft between radius and ulna.** The extensor muscles are divided longitudinally in the midline so that the common extensor to the ring and little fingers and the extensor carpi ulnaris fall toward the ulna and the extensors carpi radialis and the common extensors of the index and middle fingers fall toward the radius. On the flexor side the flexors of the wrist and the flexor sublimis are treated similarly. The flexors and extensors of the thumb and the flexor profundus are excised to reduce the bulk of the stumps. The interosseous membrane is placed under tension by separating the radius and ulna and divided near its ulnar attachment (division in the midline would result in severance of the vessels and nerves passing along the interosseous membrane). The bones are now widely separated so that there is a minimum of four inches between their ends. Hemostasis is secured. The nerves are cut short by sharp dissection so that they will be clear of future pressure areas.

3. **Muscle grouping.** Flexor and extensor muscles are now drawn over the exposed ends and sides of the bones and approximated with interrupted catgut sutures. A gutter may be created at the end of the bones if desired to prevent the covering muscle from slipping.

4. **Closure.** The radial element of the stump is closed by swinging the flaps created by the original incision toward its medial aspect where they are approximated by interrupted sutures. No skin is available for covering the exposed lateral aspect of the ulnar element. Although it may be covered by an abdominal skin flap or previously prepared tube graft, the defect is usually closed through the use of the three-quarter thickness dermatome graft. This is accurately fixed to the edges of the wound and punctured in several places near its periphery for drainage.

The wound is dressed with dry gauze and mild compression. The stitches are removed on the tenth postoperative day. Motion may be started in the stumps as soon as healing is sound, but no pressure should be placed on the grafted area until it is thoroughly fixed and vascularized (four to six weeks).

AMPUTATIONS OF THE LOWER EXTREMITY

THE FOOT

The human foot is the epitome of physiologic engineering. Its skeletal framework and the muscular forces acting upon it are so arranged that they are held in delicate balance throughout stance and gait. Alteration of the mechanics of the foot, through amputation, disturbs this balance and produces pathologic variations. A review of the fundamentals of biomechanics of the foot will clarify these concepts and lead to a clearer understanding of the basic principles involved.

The bony framework of the foot is made up of the tarsal bones (the calcaneus, talus, navicular, cuboid, and the three cuneiforms) which form the hindfoot, and the metatarsal bones and the phalanges which form the forefoot and toes. These bones are bound together by strong ligaments which stabilize the joints and play a passive supportive role during weight-bearing. The metatarsus and the bones of the hindfoot together compose a single longitudinal arch which is supported at two weight-bearing points, the metatarsal heads in the forefoot, and the weight-bearing surface of the calcaneus in the hindfoot. This longitudinal arch rises to its greatest height in the region of the mid-tarsal

joint. From this point distalward to the upper portion of the metatarsal shafts, the bones are higher on the inner than on the outer aspect of the foot, and form a domelike transverse arch.

The biomechanical interpretation of foot function has been most thoroughly explained by Morton. He points out that there are two mechanical forces acting upon the foot, (1) gravity and (2) muscular action. Stance and locomotion are the products of the interplay between these two forces. Gravity, the static force, is resisted by the inert, nontiring bone and ligaments which absorb and disseminate this load throughout the bony framework of the foot. Muscle action, the dynamic force, serves as postural control to keep the body weight balanced over freely movable joints, and provides the motor push for the foot.

These forces are transmitted throughout the foot according to definite pattern. Weight passes downward through the tibia to the talus which apportions the load applied from above. The position of the body of the talus upon the calcaneus allows the direct transmission of stresses posteriorly and laterally, while the medial deviation of the neck transmits balancing forces toward the inner border of the foot. The transverse arch is the distribution center through which the body weight is shifted to the metatarsal heads, each of which is required to take its share of the body weight. Medially the weight is transmitted through the sustentaculum tali and spring ligament to the navicular bone, and thence to the cuneiforms and the first and second metatarsals. Laterally it is transmitted through the lateral portion of the calcaneus to the cuboid and lateral cuneiform, and thence to the outer three metatarsal bones. Posteriorly, it passes downward through the body of the calcaneus to its weight-bearing surface on the heel. In *standing,* the weight is divided between the forefoot and the hindfoot. The weight-bearing surface of the calcaneus is the sole supporting element of the hindfoot. In the forefoot, weight falls equally upon the first and second metatarsal bones medially, and upon the third, fourth, and fifth metatarsals laterally, so that a line drawn in the interspace between the second and third metatarsals would represent the mid-point of the foot in regard to the weight distribution. The first metatarsal because of its size and medial position carries twice the load of any other single metatarsal head and, unlike the others, gains contact with the ground through true sesamoid bones. In *walking,* the position of the foot and the distribution of weight is somewhat different. When the foot is first placed on the ground, it is at a right angle to the tibia, and slight external rotation is present, the leg is slightly adducted from its normal standing position. As more weight is placed upon the heel, the foot descends to the floor, rotating externally at the subtalar and mid-tarsal joints, as it does so, to allow a flat contact. The weight then passes momentarily from the heel on to the side of the foot, and thence on to the firm metatarsal base. Here, it falls first on the outer portion, lightly, and then on to the medial portion, so that as the full force of weight is transmitted to the forefoot, it is supported by the first and second metatarsals. As take-off is approached, the weight passes still more medially so that it is borne by the first metatarsal alone. It thence passes distally through the great toe, which is the structure that actually consummates take-off.

When amputation is carried out in the foot, the balance between muscle and bony support is lost. This is not too important in the toes, since they are only used to any extent in rapid gait, running, and tiptoeing. In the metatarsus, however, the results of amputation are more serious, for both balance and weight distribution are destroyed in proportion to the extent and location of structural loss. Above the metatarsal bases, removal of the foot results in such profound

alteration of mechanics that the stump is practically worthless even as support for a prosthesis. In almost every instance, it is better to go to a level above the foot than to attempt amputation through it above the metatarsal bases.

Amputation Through the Great Toe

Amputation of the great toe has more crippling results than the removal of any other digit of the foot. Although it has only a minor supporting role in stance, it fulfills a vital function in gait, for it is the principal weight-bearing element in the final phase of take-off. When it is gone, that final push which adds rhythm and agility to gait is lost. This loss is felt keenly in rapid gait or running, where take-off is so important.

When amputation is to be undertaken through the great toe, the surgeon must bear in mind (1) that the stump must be supported by tough, plantar skin, and (2) that as much of the weight-bearing area as possible must be preserved. The first point is exceedingly important, for the stump supported by thin skin will be painful and will not be able to withstand weight-bearing, which, after all, is its chief function. In short, such a stump will be useless. If at any level up to the distal flexor crease, which represents the base of the interphalangeal joint, weight-bearing plantar skin is present, a useful stump may be anticipated, provided that a smooth pad and nonirritating scar are present. All available length should be saved in this area in order to afford as great a weight-bearing surface as possible for take-off. Amputation just above the distal flexor crease, i.e., through the distal end of the proximal phalanx, is undesirable for it results in the use in the weight-bearing area of the rather thin skin which underlies the head of the proximal phalanx. Rather than amputate the great toe at this level, it is better to make the incision at the level of the proximal flexor crease with the bone level through the mid-portion of the proximal phalanx, for this affords for the weight-bearing surface the tough plantar skin which underlies the metatarsal region and the proximal portion of the proximal phalanx of the great toe. At this site, pressure falls only on skin accustomed to receive it, and no thinly covered bony prominences are present.

Operative Plan

Amputation of the great toe is carried out through a long plantar and short dorsal skin flap in order that thick, tough skin accustomed to weight-bearing may be provided to cover the end of the stump. This type of flap is used regardless of the level of amputation.

Technique

The incision starts at the bone level on the mid-point of the medial side of the great toe, and passes in a gentle, distal curve over the dorsal aspect of the toe to a similar point on the lateral side. The plantar flap is tongue-shaped and is slightly longer than the dorsal-plantar diameter of the toe at the bone level. It joins the two ends of the dorsal incision. The skin flaps are now dissected upward to the bone level. The flexor and extensor tendons are sectioned and allowed to retract. The periosteum is sectioned immediately above the intended bone level, following which the bone is divided by a saw or by small bites of a rongeur or bone-biting forceps. The digital nerves are secured and sectioned slightly above the bone end. The digital blood vessels are isolated, sectioned, and tied by 000 catgut. Complete hemostasis is secured. A test fit of the skin flaps is now made, and any excess tissue is trimmed away. Care is taken to make sure that the skin is under no undue tension but rather falls into

gentle contact at the suture line. The wound is closed by interrupted sutures. No drain is instilled. Dry gauze dressings are applied, and fixed by an elastic type of adhesive for compression and collapse of dead space.

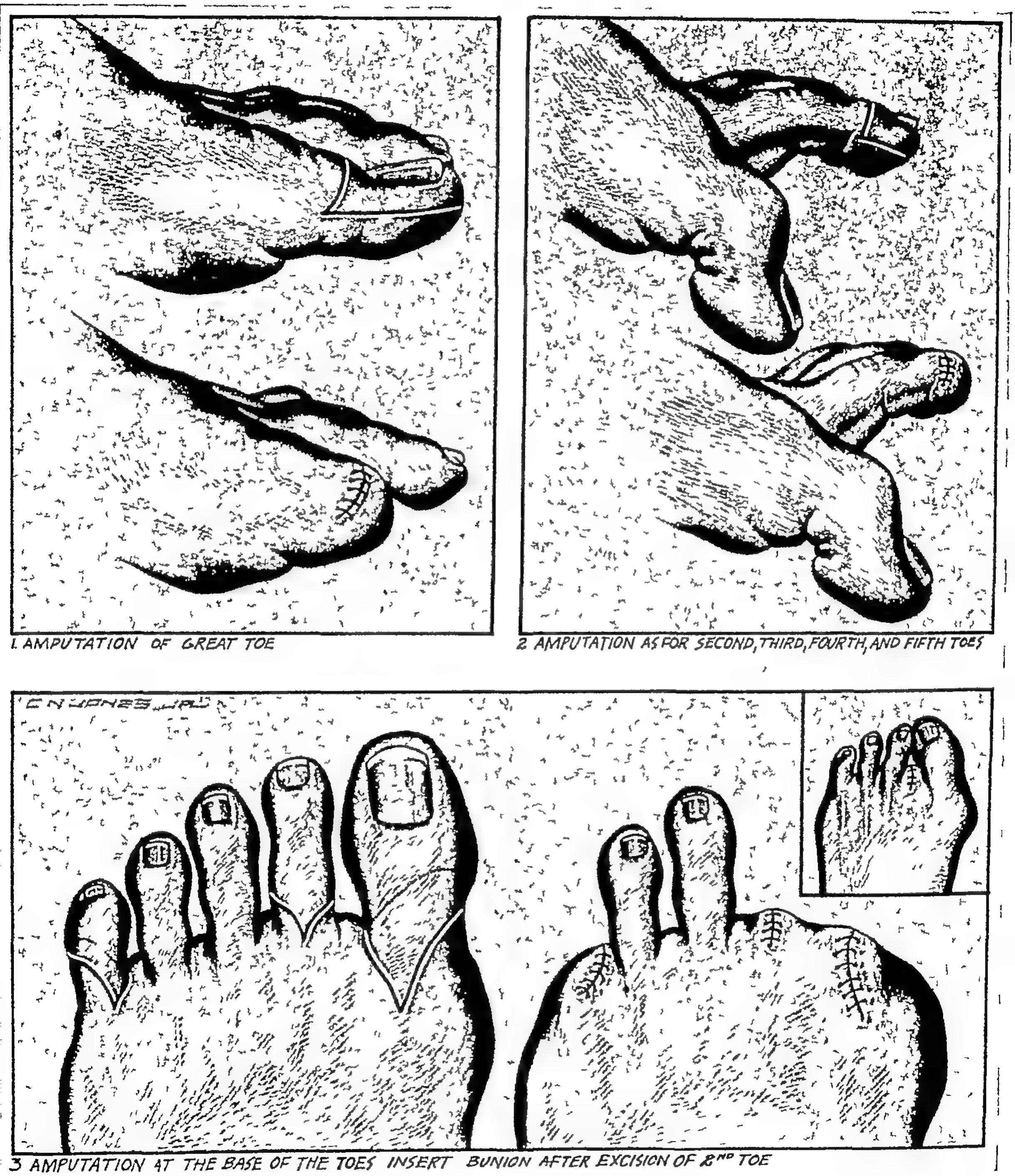


Fig. 210.—Amputation of the toes.

Disarticulation of the Great Toe

When disarticulation is to be performed at the metatarsophalangeal joint of the great toe, the chief concern is to preserve in their normal relationship the sesamoid bones underlying the metatarsal heads. The first metatarsal

sustains twice the amount of weight in stance and gait that is borne by any other single metatarsal When these two small sesamoid bones are removed from the inferior surface of the head, this normal distribution of weight is no longer ensured, and the pressure sustained by the first metatarsal may be so greatly diminished as to be negligible Thus, the proper balance of the foot is disturbed Frequently, when skin is not available for closure at the disarticulation level, it may be gained by beveling off the superior surface of the metatarsal head and a portion of the distal articular surface In this manner, the wound can be closed without further interfering with the function of the sesamoid bones As long as the sesamoid bones are retained, disarticulation of the great toe does not interfere greatly with normal gait, but it does result in an obvious limp in rapid gait or running, due to the loss of take-off

Operative Plan

Disarticulation of the great toe at the metatarsophalangeal joint varies in two respects from more distal severance of that digit (1) There is a single flap, plantar skin, which is placed in a posteromedial, rather than in the usual posterior position, in order to avoid scar over the medial aspect of the stump (2) Special precautions must be taken to maintain the sesamoid bones beneath the head of the first metatarsal

Technique

The incision starts at the midline of the dorsum of the toe at the level of the metatarsophalangeal joint, passes distally through the web space and across the plantar and posteromedial aspect of the toe, and thence proximally to join the point of origin The single flap, thus formed, has its apex on the posteromedial aspect of the toe and is slightly longer than the dorsal-plantar diameter of that part After the flap has been cut, the flexor and extensor tendons are sectioned and held with Allis clamps so that they will not retract The capsule of the joint is now divided near its attachment to the proximal phalanx, and the toe is removed The digital nerves are isolated, pulled down, sectioned and allowed to fall back in their beds Hemostasis is secured The flexor hallucis brevis is affixed to the extensor tendon by several fine silk sutures, in order to ensure that the sesamoid bones, which lie within it, will fall in their normal relationship to the articular surface of the first metatarsal and will not be displaced by its upward retraction A test fit of the skin flaps is now made, and any excess tissue is trimmed away The articular surface of the first metatarsal is not disturbed If any osteophytic formation is present on the distal end of the metatarsal, it may be rongeured away in order that a smooth, rounded surface will be presented The skin flaps are now fixed with interrupted silk sutures No drain is used Dry dressings are applied and fixed by an elastic type of adhesive or bandage

Amputations of the Lesser Toes

The principal functions of the second, third, fourth, and fifth toes are (1) to stabilize the foot by widening the base of support during squatting and tiptoeing, and (2) to assist the great toe in take-off during rapid gait and running In ordinary walking they are of little importance In itself the amputation, or partial amputation of *one* of the lesser toes, therefore, does not noticeably diminish the function of the foot Unfortunately, however, because of the peculiarities of the tissues in this area, such surgery is likely to result in a secondary deformity, such as a disabling contracture or bony prominence Such aftermaths of surgery are particularly common following section at the level of the middle phalanx and at the level of the web space In the former instance a

hammer toe frequently results and forms a painful pressure point on the end of the stump and over the dorsum of the proximal interphalangeal joint, in the latter, an extension contracture of the proximal phalanx often occurs which may be painful if it rubs against the shoe For this reason, these sites are undesirable and severance should be carried out by section through the distal phalanx or through the base of the proximal phalanx, or by disarticulation at the level of the metatarsophalangeal joint (The exception to this is in open amputation where minimal resection is the rule because of the danger of spread of infection into the fascial spaces of the foot)

Amputation of the second toe deserves special consideration Section of this toe through the distal phalanx is not disturbing, but its removal proximal to that point creates a gap between the first and third toes This routinely results *in a very marked hallux valgus deformity* because of the pull of the adductor hallucis tendon and the pressure of the shoe which, together, swing the great toe toward the third in an effort to close the gap between them This type of hallux valgus is not preventable by means of padding, strapping, taping, or transplantation of the adductor hallucis When it occurs, take-off is completely eliminated so that rapid gait and running are impaired With this deformity, it is difficult to obtain proper footwear Therefore, serious thought should be given to every case in which amputation of the second toe is considered, and such procedure should never be substituted for orthopaedic correction If amputation of this digit must be performed, it is important to save all possible length, even though this may mean section at an undesirable level *Upon this basis, amputation may have to be carried out through the* middle phalanx, and the resultant hammer toe will simply have to be corrected

Amputation Through the Distal or Middle Phalanx

OPERATIVE PLAN

Removal through a short dorsal and long plantar flap

TECHNIQUE

A transverse dorsal incision extending from the mid-medial to the mid-lateral portion of the toe is made slightly distal to the selected bone level A long plantar flap approximately one and a half times the diameter of the toe at the bone level is then outlined The flaps are reflected, the tendons are sectioned and allowed to retract, the bone is divided, nerves are sectioned, and hemostasis is secured The long plantar flap is brought upward into contact with the short anterior flap, and any necessary trimming is done It is fixed with interrupted silk sutures Dry dressings are applied

Amputation through the base of the proximal phalanx, and disarticulation of the second, third, or fourth toes at the level of the metatarsophalangeal joint are carried out in the same manner

OPERATIVE PLAN (Second, third, and fourth toes)

Removal of the toe through a dorsal racquet incision

TECHNIQUE

The incision starts at a point one centimeter above the metatarsophalangeal joint, swings downward in the midline until it passes the base of the proximal phalanx It then swings distally through the web space between the toes, across the plantar surface at the level of the flexor crease, and then upward through the opposite web to join the midline incision near the base of the proximal phalanx Skin flaps are reflected away from the deeper structures, and the tendons are severed and allowed to retract Adequate tendon length can be assured by sectioning the extensor tendon in full extension and the flexor tendon in full flexion The remainder of the soft tissues are sectioned The

bone is now either divided at the base of the proximal phalanx or disarticulated by section of the articular capsule, and the toe is discarded The nerves retract above the bone level, and hemostasis is secured The skin is approximated by interrupted sutures Dry dressings are applied, and a compression dressing of elastic adhesive is used

Disarticulation of the fifth toe is the most frequent of toe amputations It is usually carried out for cosmetic reasons, or to provide better fitting of the foot in the shoe

Operative Plan

A single lateral or dorsolateral flap with its base at the bone level is used to keep the scar away from all weight-bearing and pressure areas

Technique

The medial portion of the incision passes through the web space along the base of the toe from its dorsal to its plantar surface From either end of this wound, the incision is carried distally along the lateral side of the toe to form a lateral or anterior-lateral flap, which should be of sufficient length to cover the defect left by the removal of the toe The skin flap is then reflected backward, the tendons are sectioned, and the nerves are identified, sectioned, and allowed to retract The capsule of the joint is incised circumferentially, the toe removed, and complete hemostasis secured The skin flap is allowed to fall in position, which it does in the same manner that a lid falls on a fishing creel Any final trimming is done at this time, and the skin edges are approximated by interrupted suture A dry compression dressing is applied with an elastic type of adhesive

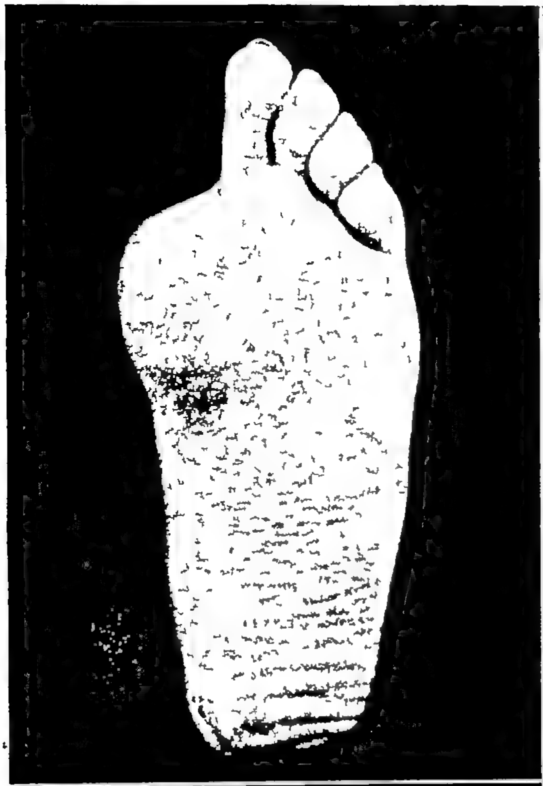
Disarticulation of two or more adjacent toes at the metatarsophalangeal joint may be carried out through one wound, with the plantar flap slightly longer than the dorsal On the plantar aspect, an elliptical incision extends along the flexor creases of the toes and distal portion of the intervening web from the medial side of one toe to the lateral side of the other The dorsal incision arises at one terminus of the plantar incision, traces an ellipse across the toes at the level of the distal edge of the web space, and joins the other terminus of the plantar incision The remainder of the technique is the same as that for disarticulation of a single toe

Amputation Through the Metatarsus

Amputation through the metatarsus may result in serious functional disability and, therefore, should not be undertaken without serious consideration of the alterations in support and balance which may follow These changes are dependent upon the structural loss of the supporting surfaces of the metatarsal heads, and the loss of muscular attachments in the metatarsal region The metatarsal heads represent the anterior weight-bearing pillar of the foot The broad surface of this pillar is supplemented by thick, tough, plantar skin which, in addition to its cushioning action, adds breadth and stability to the ball of the foot Removal of one or more of the metatarsal heads results in a proportionate loss of stability in the foot, and necessitates the redistribution of weight in this area The loss of the skin underlying them also decreases the anterior supporting area and for this reason, it should be preserved, wherever it is possible, even though the heads themselves must be sacrificed The tendinous insertions equalize the muscle pull on the two sides of the foot, and their loss creates muscle imbalance Narrowed weight-bearing surface and muscle imbalance, either singly or in combination will result in deformity This in turn will alter the efficiency of gait through changes in the weight distribution pathways and the area of support and through the inability of the foot to fit in a shoe

THE EFFECT OF AMPUTATION UPON THE SUPPORTING SURFACE OF THE FOOT

211



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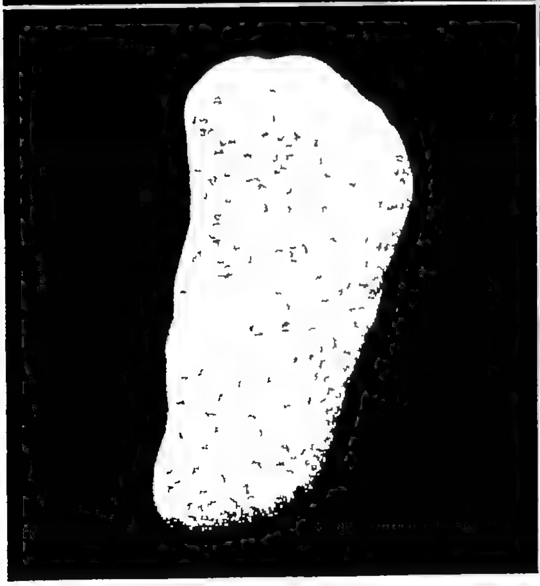

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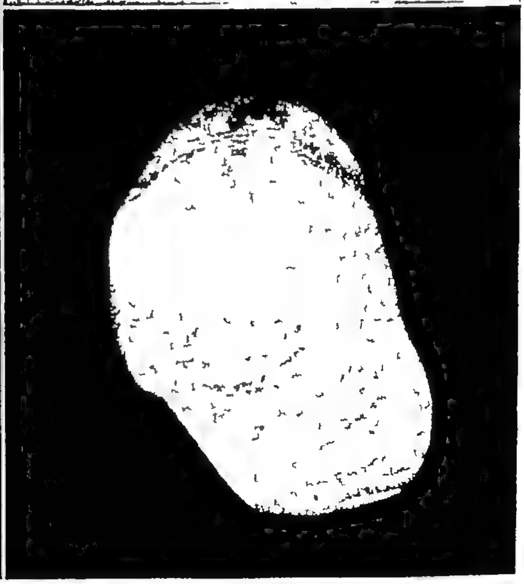

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(For legends see opposite page)

Fig 211 —Amputation of the great toe has little effect upon standing, where it plays only a minor supporting role In walking, where it contributes to take off, its loss is felt more keenly with increasing speed of gait (Walter Reed General Hospital Neg No 4839 6)

Fig 212 —Disarticulation of all toes at the metatarsophalangeal joints, still affects standing but little However, it results in the complete loss of take off so that the speed of gait is limited and tiptoeing is not possible (Walter Reed General Hospital Neg No 4618 3)

Fig 213 —In mid metatarsal amputation the loss of the metatarsal heads removes the anterior pillar of support so that the front of the foot drops and is supported by the shafts of the metatarsals resting on a base of tough plantar skin While the breadth of the forefoot still affords excellent stability against medial or lateral deviation, and standing support is satisfactory, there is considerable disturbance in gait This last occurs because of the loss of take off and because of the substitution of the metatarsal shafts for the metatarsophalangeal joints as the center of rotation as the heel is lifted from the ground (Walter Reed General Hospital Neg No 4366 2)

Fig 214 —In transcuneiform amputation immediately above the tarsometatarsal joints, the distal end of the stump drops to the floor, in a position of moderate equinus, to gain support from the undersurface of the cuneiform bones Lateral stability is lessened, since the supporting surface is narrow, and is especially precarious if the lateral stabilizing muscles are not reattached In walking, the gait is awkward and the complete loss of take off, together with a marked posterior displacement of the anterior supporting surface, shortens the stride and causes a lifting motion of the foot as it is advanced for the next step (Walter Reed General Hospital Neg No 4865-1)

215

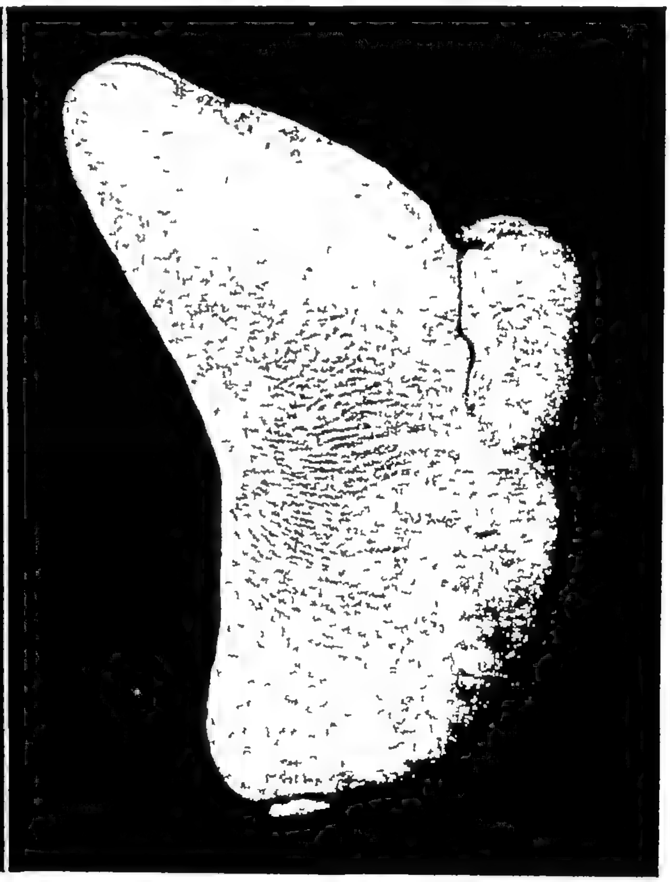

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Fig 215 —When the outer portion of the foot is amputated and only the first metatarsal remains, the lateral portion of the anterior pillar of support is gone and the foot tends to be thrown into inversion as weight is borne upon it, in addition, take off is lost (Walter Reed General Hospital Neg No 4624 2)

Fig 216 —Trans metatarsal amputation with bony deformity (as in this case with marked deviation of the first metatarsal bone) possesses all the disadvantages of amputation at this level, and in addition causes a disturbance in balance and precludes the use of ordinary footwear (Walter Reed General Hospital Neg No 4689 3)

The type of skin used in amputations through the forefoot deserves special attention because of its effect upon function. The sole of the foot should be covered with a good, thick layer of plantar skin with adequate sensation in order to withstand the trauma of constant weight-bearing. If the skin is thin or anesthetic, it usually will break down with use. For this reason, the use of skin grafts obtained from other body areas must be restricted to nonweight-bearing, nonpressure areas. The use of free split-thickness grafts is limited to temporary wound coverage in all instances except those in which it is protected from pressure by the surrounding structures. Wherever possible, suture lines should be placed to the side of the foot just below the dorsal margin so that they will not be subject to pressure or friction from the sole and vamp of the shoe. If plantar scars are unavoidable, they should be thin and linear in type, and should be provided with a base of subcutaneous fat in order to prevent adherence to the underlying structures. If this cannot be accomplished, it is better to have a deeply inverted scar which is not subject to direct pressure. This latter type may, of course, be subject to intertrigenous irritation and fungus infection.

Amputation Through the First Metatarsal

The first metatarsal is the most important of all the metatarsal bones, for not only does it bear twice the weight of any other in standing, it also carries at least half of the entire body weight at the moment immediately before the foot leaves the ground. The head of the metatarsal bone does not transmit weight directly to the ground, the sesamoid bones lying in the tendon of the flexor hallucis brevis are the intermediaries. When the head of the first metatarsal is removed, the weight normally borne by it is transferred to the second metatarsal; this results in hypertrophy of that bone, often accompanied by painful calluses beneath its head. In addition, since the normal pull of the long flexor and extensor tendons of the great toe is lost, the foot tends to roll inward and downward in an effort to reach a supporting surface, and this results in a valgus deformity of the foot. The greater the bone loss, the stronger is this tendency. It can be somewhat inhibited by the use of arch supports and partial prosthesis.

Operative Plan

Amputation through the first metatarsal is carried out through a dorsal racquet incision so that the suture line will fall on the dorsomedial aspect away from any pressure area.

Technique

The incision starts at the anticipated bone level, passes downward over the dorsal aspect of the metatarsal shaft, swings slightly laterally to pass through the web space between the first and second toes, and goes transversely across the flexion crease of the great toe to its medial aspect. From there it swings upward to join the original incision at a point slightly distal to its terminus. The incision is then deepened to bone. The metatarsal is sectioned at the desired level, and the tendons are severed and allowed to retract. The muscle belly of the abductor and short flexor of the great toe are sectioned just distal to the bone level, and the nerves are identified, cut short, and allowed to retract. Hemostasis is secured, and the medial flap is approximated to the lateral one. Any redundant edges of skin are trimmed away. Fixation is carried out by interrupted sutures. Dry dressings are applied, and elastic bandage compression is used. The elastic bandages with adhesive backing are usually best in this region.

In amputations at the distal end of the metatarsal, the weight-bearing surface of the head may frequently be preserved by a special plastic procedure designed to afford adequate skin for closure This is effected by beveling the dorsal and medial aspects of the head The osteotome is placed at the junction of the lower third of the articular surface with the upper two-thirds, and is then carried upward and backward a distance of about three-quarters of an inch This will decrease the area which the skin has to cover If closure of the entire area cannot be accomplished, an auxiliary free split-thickness skin graft may be used

Amputation Through the Second, Third, or Fourth Metatarsal

Amputation through either the second, the third, or the fourth metatarsal bone affects the function of the foot far less than amputation through the first metatarsal The balance of the foot is not altered since its breadth is unchanged and only minor muscles are divided, the heavy plantar skin, supported by adjacent metatarsals and heavy fascial bands, aids in transferring the weight-bearing function to the neighboring force pathways The foot, however, will be slightly weaker due to the loss of the single weight-bearing point represented by the metatarsal head This will be more pronounced in the instance of the removal of the second metatarsal bone, and if the neighboring first metatarsal is short and hypermobile, the inevitable hallux valgus of the great toe will ensue as described under the section on amputation of the toe There is one sequela which may follow amputation surgery involving any of these metatarsals, and that is a painful plantar scar Ordinarily this may be avoided by employing a type of incision which will not lie in the pressure area In some instances, however, plantar extension of the scar may be necessary When this is the case, it should be allowed to become inverted so that it will not be subject to direct pressure

Operative Plan

A dorsal racquet incision is used so that the suture line will fall on the dorsal aspect away from any pressure area

Technique

The incision starts at the desired bone level and extends downward over the dorsal aspect of the metatarsal shaft to the level of the metatarsal-phalangeal joint At this point, it passes distally through the web space to cross the undersurface of the toe at the level of the proximal flexion crease Thence, it sweeps through the other web space and passes upward to join the dorsal incision over the metatarsal-phalangeal joint The incision is carried to bone Flexor and extensor tendons are divided at the upper extremity of the wound The bone is sectioned with a Gigli saw The digital nerves are cut at the point where they pass to the involved toe Hemostasis is secured, and the wound is closed by interrupted sutures No drain is used A pressure dressing is applied

Amputation Through the Fifth Metatarsal

Amputation through the distal two-thirds of the shaft of the fifth metatarsal results in very little residual disability In fact, this portion of the bone is frequently removed in bone surgery to be used as a bone graft in hand reconstruction Its weight-bearing function is minimal, for its supporting phase is only momentary and is cushioned by the normal upward motion caused by the flexibility at the metatarsal-cuboid joint If the whole shaft is lost, however, function is more seriously impaired In this instance, the entire lateral supporting surface of the foot is removed, and there is a muscle imbalance due to the loss of the tendons of the peroneus brevis, and often the near-by peroneus

longus This results in a weak and unstable foot with a tendency toward inversion It is self-evident that, whenever possible, the upper end of the fifth metatarsal should be left intact

Technique

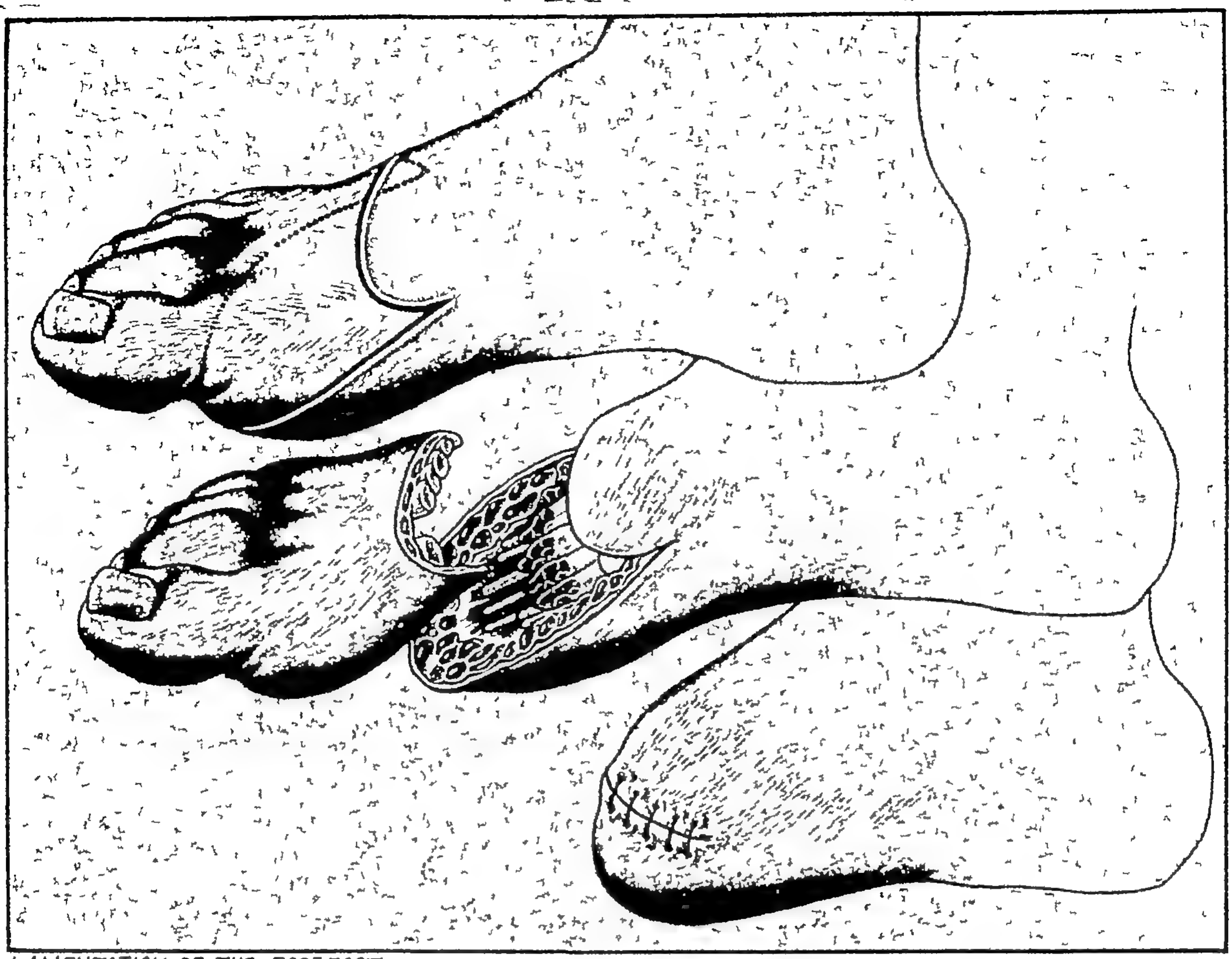
A dorsal racquet incision is utilized The incision passes downward over the shaft of the fifth metatarsal, and swings through the web space between the fourth and fifth toes Thence, it sweeps laterally around the side of the toe, or metatarsal shaft, depending upon the level at which the metatarsal is to be removed, to join the dorsal incision The incision is then deepened to bone, and bone section is accomplished at the desired level Tendons, muscles, and other soft tissues are divided, and the nerves are drawn down, sectioned, and allowed to retract The periosteum is trimmed so that no loose tags will be present Closure is effected by approximation of the lateral flap to the medial one, trimming of the skin for anatomic closure, and fixation with interrupted skin sutures

Multiple Metatarsal Amputation

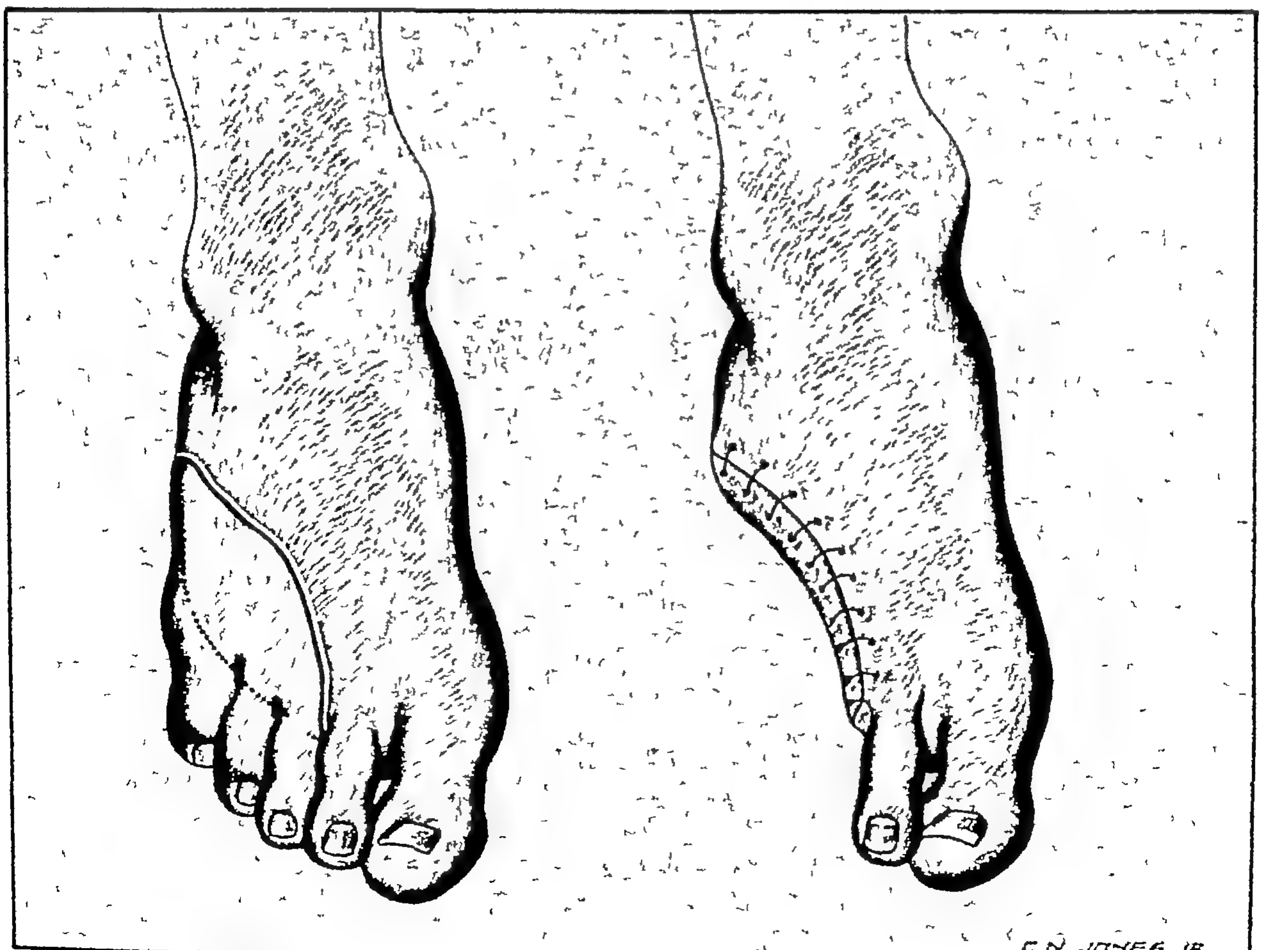
Amputation of more than one metatarsal results in much greater functional disability than does the removal of a single ray With the greater structural loss the supporting elements are lessened, and the balancing effect of the muscles is diminished The spring action of the foot in take-off is destroyed whether it be the medial or the lateral metatarsal elements which are removed If the inside portion of the forefoot is amputated, the actual base of support and spring is lost, if the outer portion is removed, the synchronous transfer of weight from the outer to the inner border of the foot, so essential to take-off, is sacrificed

There is one point which should be stressed If a serviceable foot is to be obtained, all *useful* bone length should be saved The greater the extent of the bony architecture preserved, the greater will be the functional worth of the amputation stump, and the more readily will it be adapted to the shoe or partial prosthesis It must be said in this regard, however, that it is futile to preserve portions of bone projecting beyond the weight-bearing area of the stump, since these serve no useful function, and their skin covering is usually thin, fragile, and subject to breakdown on minor trauma

Amputation of the medial side of the forefoot results in a tendency toward valgus which is increasingly evident with the loss of each ray and of each fraction of length within a ray Here, in contrast to comparable surgery in the hand, the cosmetic considerations are minor, and the maintenance of a greater bearing area is the primary aim Therefore, the metatarsal bones should be maintained at their maximum length commensurate with adequate skin coverage, and no attempt should be made to form an even, sloping contour by further bone resection The skin should be preserved as long as there is adequate bony backing for it, and a mass of plantar skin should be saved even though it does not have bone directly overlying it, for the sake of the stability which it will afford (Loose redundant skin tabs should, of course, be eliminated) By like reasoning, when amputation must be undertaken through all four medial metatarsals, it is advisable to maintain the fifth metatarsal bone The fifth toe, however, may prove a source of trouble it may be deformed, it may, even though perfectly normal, be the cause of annoyance because of its protrusion beyond the rest of the stump, frequently it may interfere with the wearing of shoes and socks and, in some instances, with the use of a prosthesis Whenever it is in the way and results in awkward or painful gait, it should be amputated Patients with the loss of two three, or four medial metatarsal bones will often walk surprisingly well if provided with shoes which have thick, stiff soles, and an insole type of prosthesis



1. AMPUTATION OF THE FOREFOOT



2 PARTIAL AMPUTATION OF THE FOREFOOT

Fig 217

Amputation of the lateral side of the forefoot has essentially the same considerations as that on the medial side. When amputation of the lateral four metatarsals is performed, but the great toe is left, there may be a problem. Usually this toe will be fixed by scar in its normal position. If this does not occur, however, the loss of the adductor hallucis and ligamentous fixation to adjacent structures and the tendency to varus deformity may cause the great toe to drift into medial deviation. Should this complication be at all extensive, there may be difficulty in wearing a shoe. This should be corrected by appropriate orthopaedic measures.

TECHNIQUE

It is difficult to standardize a technique in a procedure which demands, as its basic concept, the preservation of all possible length. The operation is ideally carried out with a long medial plantar flap (or lateral plantar if the outer side of the foot is to be removed). In this way weight-bearing pressure may be cushioned by the plantar skin, while the short dorsal flap allows the suture line to fall just below the pressure of the shoe from above. Once the flaps are cut (and they are usually somewhat irregular), the bones are sectioned at a level where they may be covered by normal healthy skin. No effort is made to sew the tendons to the end of the stump, they are simply identified, sectioned, and allowed to retract within their sheaths. If the tendons stabilizing the foot, either medially or laterally, are encountered, they should be inserted at a point where they may remain effective in their stabilizing action (i.e., the peronei). Since the plantar skin will form adequate protection for the terminus of the stump, the plantar muscles are trimmed away to a point where they fall flush with the bone ends. The nerves are sectioned above the bone level, and complete hemostasis is obtained. The plantar flap is then drawn upward over the open surface of the wound and approximated to the dorsal flap without tension. Dry dressings are applied without drainage, and mild compression is employed. The stitches are removed on the tenth to fourteenth day.

Transmetatarsal Amputation

Transverse amputation of the forefoot through all the metatarsals results in a surprisingly good walking foot, although the ease and efficiency of gait decreases progressively at each successively higher level of amputation. The tendency toward medial or lateral deviation is absent, following this type of operation, due to the symmetry of the shape of the stump and of the muscle attachments. In spite of this, the functional result is seldom as good as that following partial forefoot amputation at a similar level.

OPERATIVE PLAN

Surgery is performed on the principle of the long plantar and short dorsal flaps.

TECHNIQUE

To form the dorsal flap, the incision starts just above the saw level at a mid-point on the medial aspect, and passes across the dorsum of the foot immediately distal to the anticipated bone level, to a similar point on the lateral aspect of the fifth metatarsal. The plantar incision starts at the point of origin of the dorsal incision, and swings downward across the medial aspect of the head of the first metatarsal, crosses the bottom of the foot at a level with the other metatarsal heads, and passes slightly upward to join the lateral end of the first incision. In forming the plantar flap, it should be remembered that the cross section of the medial side of the stump is greater in depth than that of the lateral side of the stump and, therefore, the flap must be longer in this

region. A longer dorsal flap may be made if adequate plantar skin is not present, but the plantar skin should come up as far as the bone level on the inferior surface of the foot, since dorsal skin is not ideal for weight-bearing. The dorsal incision is now carried to bone, and section of the extensor tendons is carried out in such a manner that they will retract above the wound edge. The incision on the plantar surface of the foot is carried down to the bone, and the flexor tendons are severed. The plantar skin is dissected slightly above the level of bone section, and a flap is formed consisting of plantar skin, subcutaneous fat, and a thin, beveled layer of plantar muscles. The intrinsic muscles of the foot are severed at the bone level, and the metatarsal bones are sectioned parallel to the tarsometatarsal joints. All loose tags of periosteum are removed. Nerves are isolated, sectioned, and allowed to fall back in their beds above the line of bone section. Hemostasis is secured. Skin flaps are approximated, trimmed, and closed with interrupted sutures. The skin on the sole of the foot, like that on the hand, heals slowly and, therefore, the sutures should not be removed for a period of two weeks. A drain is instilled in the side of the wound if there is considerable oozing. Dry dressings are applied, followed by an elastic bandage. To prevent equinus contracture, the foot is immobilized by a plaster of Paris splint along the posterior aspect of the leg, or by a short leg cast with the ankle joint at right angles.

Amputation Through the Tarsus and Ankle

Amputations through the tarsus and through the ankle are considered together because the surgical objective in each instance is the same, namely, to provide an end-bearing amputation stump. Such a stump must have a broad stable bony base and be covered with normal weight-bearing skin. The success of these procedures is measured in terms of the stump's capacity for normal, painless weight-bearing, and its adaptability to a prosthesis. Amputations in this area are indicated only when the circulation is good, the sensation intact, and an adequate supply of plantar weight-bearing skin is available. They should seldom be performed in women, because of the unsightly appearance of the large, bulky stump within the prosthesis, but are primarily of use in the young, active male patient. The level of amputation within this area must be carefully considered upon the basis of ultimate function, with an eye to the technical difficulties of the operation, and the question of whether a simpler procedure at a higher site would accomplish the same result. In view of the future utility of the stump, sacrifice of bone length may be justified, and amputation through the leg may be advisable. Of all the amputations between the metatarsals and the ideal below-knee level, the Syme is the only one which is satisfactory in routine use and creates a stump which is broad and end-bearing with plantar skin covering, and which is also adaptable to a prosthesis. In certain instances where a prosthesis is not anticipated, the Boyd and Vasconcelos amputations may be considered. The Pirogoff, in its modified versions, may be of occasional value, but possesses neither the ability to be fitted with an artificial foot which qualifies the Syme amputation, nor the broad weight-bearing surface for use without a prosthesis which is present in the Boyd and Vasconcelos. The amputations at the mid-tarsal and metatarsal-tarsal levels are generally unsatisfactory.

The Syme Amputation

The Syme is an amputation in which the bone level is immediately above the ankle joint, and the bone end is clothed by the tough plantar skin which normally covers the heel. It is designed for direct weight-bearing on the end of the stump. It is one of the few lower extremity amputations which will

withstand the trauma of stance or gait over a period of years without breakdown The long lever arm provides power and control, while the flaring bulbous end of the stump provides stability for the prosthesis The length of the stump allows sufficient clearance between its end and the floor to provide room for an ankle mechanism within the prosthesis, but it is still long enough so that it may be used without a prosthesis when required This latter point is of considerable comfort to the patient, for it allows him to walk about in his home without hopping on one foot at times when the prosthesis would not normally be worn This is particularly true when the patient must rise at night There are two points which should be stressed in regard to the Syme amputation (1) It should never be done in the presence of vascular disease, for the nutrition of the stump would be inadequate (2) It is a final reconstructive procedure and always follows a primary amputation at a lower level in the foot As an elective final operation it requires absolute cleanliness, for even minimal infection may destroy the future utility of the stump

Preoperative Care If the original amputation has been of the open type, it must be prepared according to the technique described in the section on Open Amputation The granulating bed must present a clean, firm, cherry-red appearance, and the surrounding skin must be soft, pliable, and free from all evidence of edema When the open wound lies near the anticipated incision for the Syme procedure, it is advisable either to allow it to heal or to close it temporarily with a split-thickness skin graft Preoperative x-rays should always be taken so that any disturbance in the integrity of the normal bone structure may be predetermined

Technique

1 *The incision* starts at the most distal tip of the lateral malleolus and passes upward across the front of the ankle joint at the level of the distal end of the tibia It then passes to a point one fingerbreadth below the most distal tip of the medial malleolus From this point, it proceeds vertically downward at right angles to the bottom of the foot, crosses the sole, and thence upward to the starting point of the incision immediately below the lateral malleolus All structures are now divided to bone

2 *Excision of the tarsus* The ankle joint is now exposed anteriorly It is disarticulated through section of its capsule and supporting ligaments The knife is placed in the joint space between the medial malleolus and the talus and drawn downward beside the talus until section of the deltoid ligament is complete The calcaneofibular ligament is sectioned in a similar manner The foot is now forced into acute plantar flexion, and a bone hook is inserted in the posterior articular surface of the talus to facilitate further equinus The posterior capsule of the ankle is severed, and then, with the knife hugging the bone closely, dissection is carried backward toward the posterior aspect of the calcaneus As the dissection continues, forward flexion of the foot is increased until the tendo Achillis comes in view This is sectioned at its insertion Care should be exerted at this point to insure that the knife blade is close to bone, because the skin may be easily buttonholed at this point The bone hook is now dislodged from the posterior aspect of the articular surface of the talus, and placed in the posterior aspect of the calcaneus Dissection is continued, to free the calcaneus from the plantar tissues The entire foot, with the exception of the heel flap, is now removed

3 *Bone section* The skin and deep fascia are reflected upward on the anterior aspect of the leg and soft tissues are divided to bone The malleoli are exposed extraperiosteally, and soft tissue is reflected away from the posterior

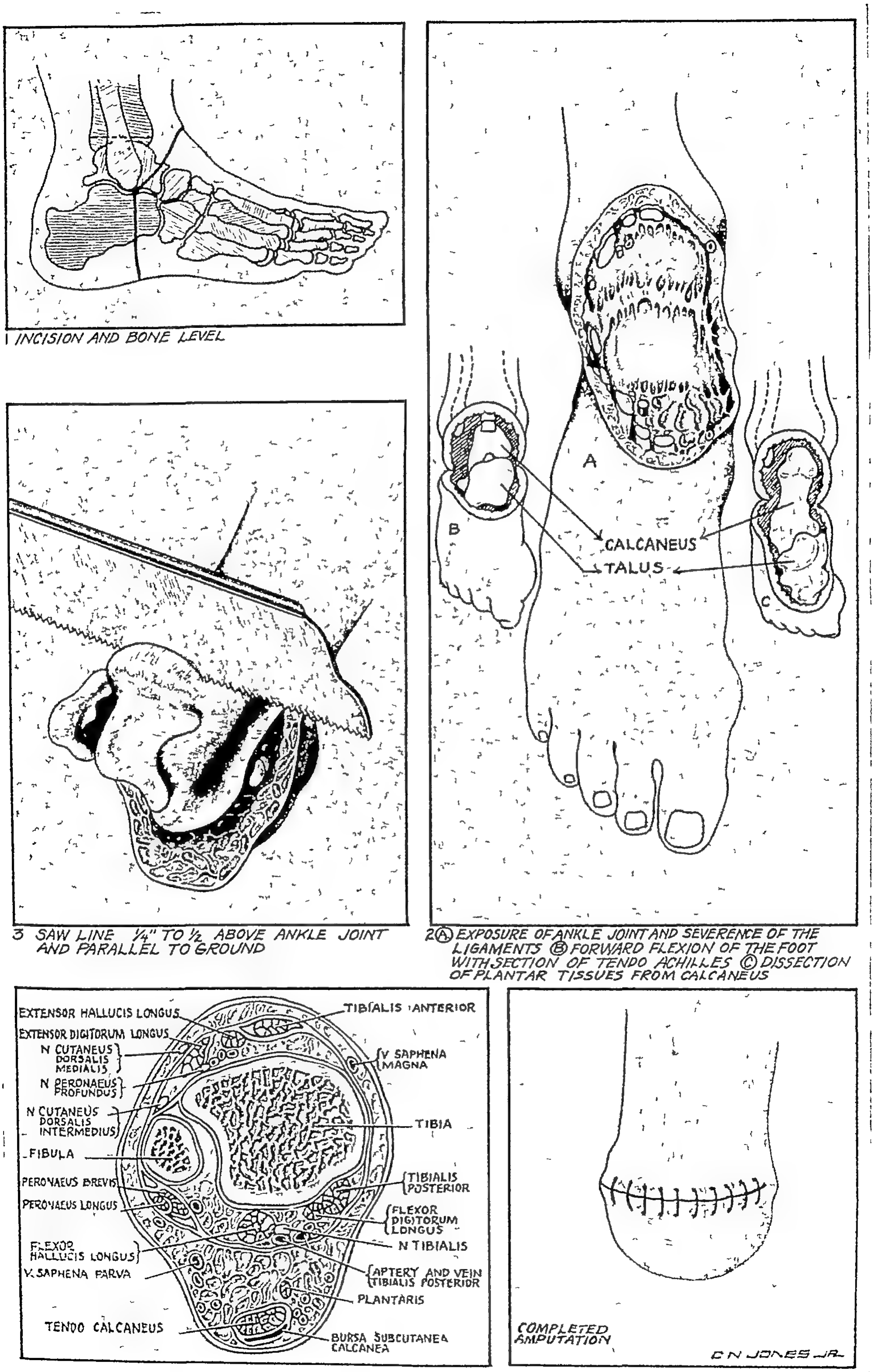
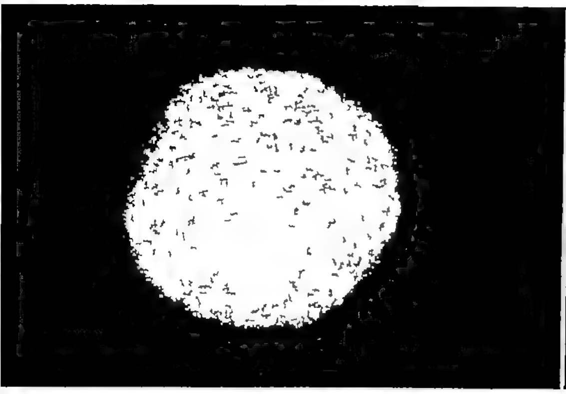


Fig 218 —Technique of Syme amputation



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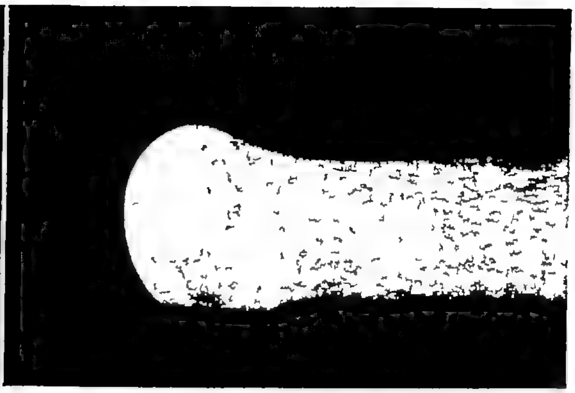

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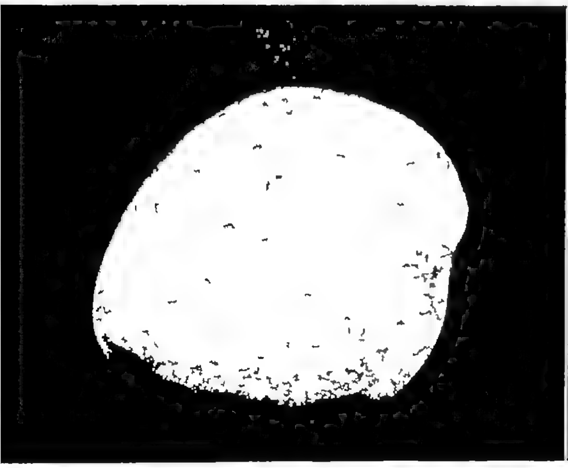
Figs 219 and 220—Terminal and lateral views of typical Syme stump Note the posterior flap, anterior suture line, and broad weight bearing surface (Walter Reed General Hospital Neg No 4856 3,1)



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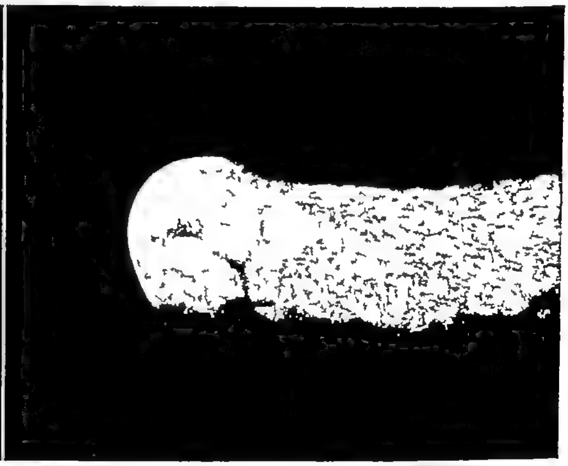

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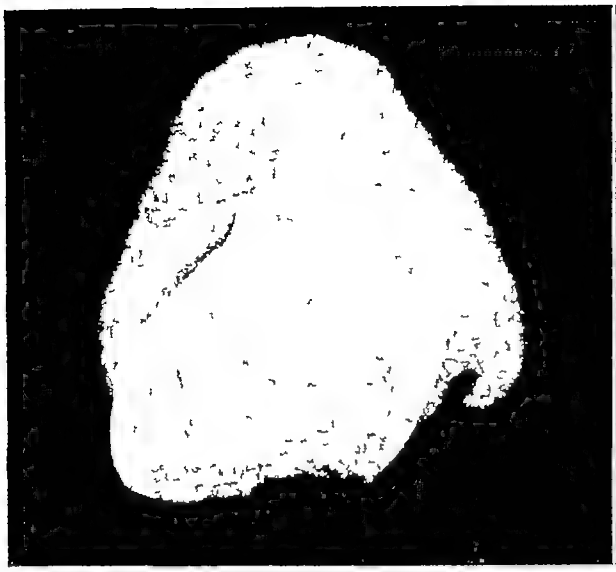
Figs 221 and 222—Terminal and lateral views of atypical Syme amputation Note the anterior flap, posterior suture line, and broad well padded weight-bearing surface The hair on the flap at the posterior aspect of the stump designates the skin used for this purpose originated from the dorsum of the foot (Walter Reed General Hospital Neg No 4667-2,3)



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Figs 223 and 224—Terminal and medial views of atypical Syme amputation Note the lateral flap, medial suture line, and excellent weight bearing surface (Walter Reed General Hospital Neg No 4895 3)

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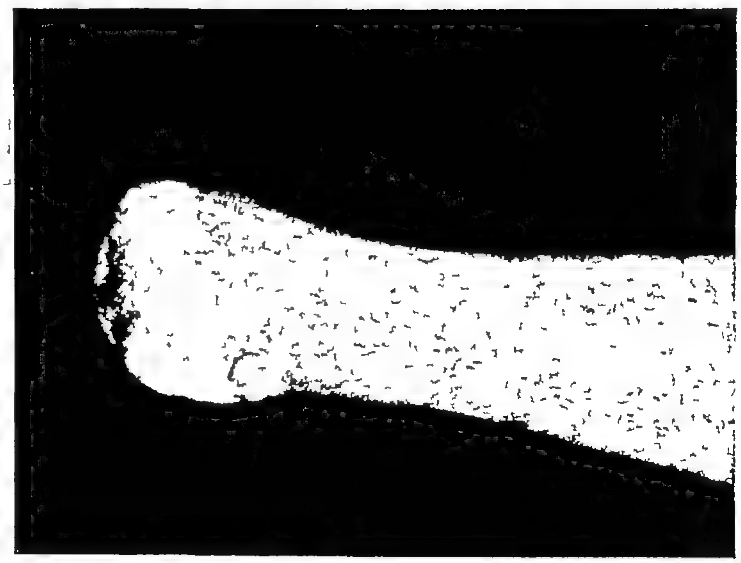

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Figs 225 and 226—Terminal and lateral views of atypical Syme amputation Note the medial flap, lateral suture line, and broad weight bearing surface (Walter Reed General Hospital Neg No 4685 3,2)

aspect of the tibia immediately above the articular surface The saw line is placed one-quarter inch above the distal anterior end of the tibia, in such a manner that it would be parallel to the ground were the patient in the standing position As the bones are sectioned, the saw will pass through the top of the concavity of the articular surface of the tibia, leaving a layer of articular cartilage about the size of a ten-cent piece All sharp corners are rounded and smoothed

4 *Care of the soft tissues* All tendons are identified, pulled down, and sectioned at the level of the end of the bone with the exception of the tendo Achillis which is not disturbed further The neurovascular bundle is identified, and the medial and lateral plantar nerves are dissected free to a point where they become the tibial nerve They are then drawn downward, sectioned, and allowed to fall upward in their beds above the saw level The posterior tibial artery and vein are identified and ligated just above the end of the heel flap The anterior tibial artery is identified, and doubly ligated All cutaneous nerves are isolated, drawn down, sectioned, and allowed to fall back in their beds Complete hemostasis is secured The heel flap is débrided of all remaining muscle and fascia, and is then approximated to the anterior skin and fixed with interrupted skin sutures Any subcutaneous fat that interferes with accurate approximation is removed Drains are placed near the medial and lateral ends of the closed wound Large "dog ears" of skin are present at both extremities of the suture line, but these should not be removed inasmuch as they furnish a large share of the blood supply to the skin flap and will disappear later under bandaging A dry gauze dressing is applied Adhesive tape strips are used to hold the heel flap in position over the end of the bone so that it will not drift toward the posterior-medial aspect of the stump Elastic bandages are carefully wrapped about the stump to hold it in the proper position

Postoperative Care The wound is dressed at the end of forty-eight hours, at which time one of the drains is removed The second drain is taken out after three or four days The leg is elevated for postural drainage Stitches may usually be removed at the end of fourteen days Elastic bandaging is continued until the end of the third or fourth week, at which time a walking cast is applied, and maintained until shrinkage is complete Measurements for the prosthesis may be taken then, and a walking cast reapplied until the artificial limb is constructed

The Atypical Syme Amputation

Not infrequently, circumstances do not favor the performance of the Syme amputation in the classical manner The wound may be such that it infringes upon the plantar skin which is normally utilized as covering for the bone end The excellence of the Syme amputation stump in young adult males, however, has led the writer to carry out the procedure by the use of unconventional skin flaps in some such cases Any variation in method must fulfill the basic requirements of the true Syme, if the results are to be successful The bone end must be parallel to the ground and present a broad surface with rounded margins, the skin covering the bone end must have good nutrition and sensation, and must be capable of withstanding the trauma of weight-bearing, the suture line must be placed where it is not subject to pressure or irritation In those cases in which the author has performed an atypical Syme amputation, the skin used as a substitute for the heel flap has had excellent nutrition because of collateral circulation In six instances the use of a long medial flap of plantar skin and a short lateral one has had favorable results, and in one case long lateral and short medial plantar flaps were utilized successfully In one patient good results followed the use of an anterior flap which included a large pad of subcutaneous

fat from the anterior aspect of the ankle joint A Syme amputation should be undertaken with these variations only after thorough evaluation, and with an understanding of the risk of secondary breakdown

The Boyd Amputation

The Boyd amputation is based on the principle of direct weight-bearing on the calcaneus following the removal of the remaining bones of the foot and calcaneotibial arthrodesis It is the procedure of choice when amputation is indicated through the tarsus or ankle and a prosthesis is not to be used The bulky, well-padded surface of the heel is maintained intact and affords an excellent base for weight-bearing The stump resulting from this amputation is longer than that of the Syme and thus allows closer contact with the floor It is possible to construct a prosthesis for this stump by substituting for the ankle mechanism an exaggerated metatarsal break in the foot piece, but usually an "Elephant Boot" is worn in lieu of any such device From the surgical viewpoint, the Boyd procedure is somewhat more technical than the Syme and requires more skin for closure, there is always the possibility that the bony fusion between tibia and calcaneus may fail

Operative Plan

Excision of all bones of the foot save the calcaneus, which is fused to the tibia and covered by a plantar skin flap from the heel, to form a weight-bearing surface

Technique

1 *Incision* The incision starts immediately beneath the tip of the external malleolus, and passes dorsally over the foot to a point overlying the talonavicular joint, and thence medially to a site one fingerbreadth below the internal malleolus From this point the incision swings downward toward the sole of the foot and crosses the plantar surface, skirting the metatarsal bases Its final limb ascends the lateral aspect of the foot to the point of origin The incision is then deepened to bone

2 *Removal of bony elements and preparation for arthrodesis* The ligamentous attachments to the calcaneus and tibia are divided by sharp dissection, the knife being kept close to bone at all times The bones of the foot, with the exception of the calcaneus, are now excised The anterior tarsal bones may be removed from the talus first, or they may be left for use as a handle in manipulating the talus during its excision The actual technique of removing the talus is like that described by Whitman The anterior portion of the calcaneus is divided in the anterior posterior plane just distal to the peroneal tubercle (trochlea) The superior surface is denuded of all investing cartilage, and adapted for arthrodesis The tibia is cleared of its cartilaginous surface and is shaped to fit the calcaneus

3 *The care of the soft tissues* The tendons are drawn down, sectioned, and allowed to retract within their sheaths The medial and lateral plantar nerves are isolated and sectioned at a level where they will not be subject to pressure The cutaneous nerves in the anterior flap are identified and sectioned so that they will fall well above the suture line All redundant tissue is trimmed away The medial and lateral plantar arteries are isolated, sectioned, and tied The tourniquet is removed, and thorough hemostasis is secured

4 *Final step* The calcaneus, which lies within the heel flap, is now mortised into position for arthrodesis, with its undersurface parallel to the ground Care should be taken that it is shifted forward on the tibia so that it is better situated to receive the weight from above The position may be stabilized by a Stein-

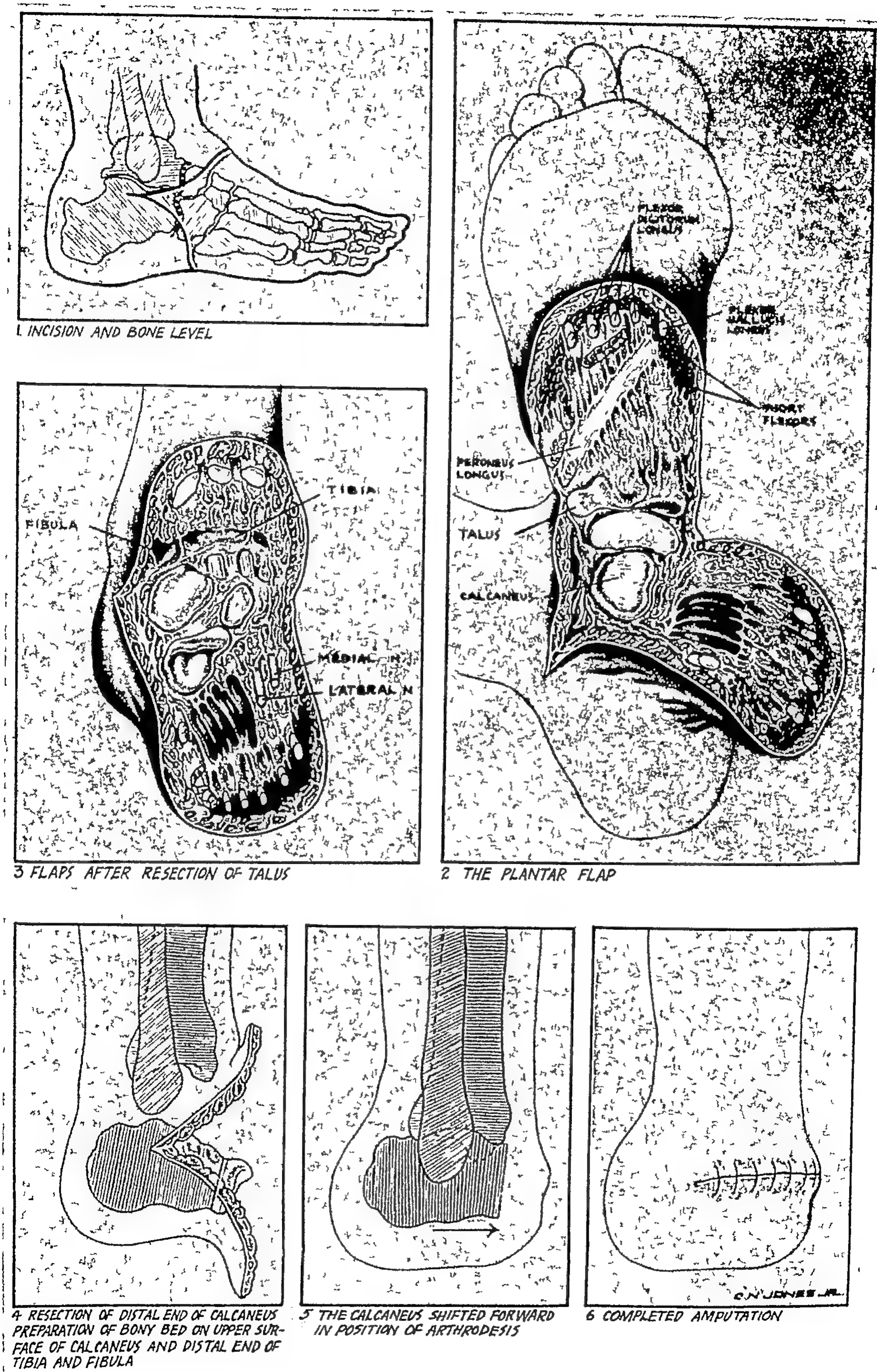

Fig 227 —Boyd amputation

mann pin passing upward through the heel, or by a Kirschner wire passing through both malleoli and transfixing the calcaneus. The skin flaps are approximated and fixed with interrupted sutures. A drain is inserted near the end of the suture line, and dry dressings are applied. A plaster of Paris splint is put on for protection and stabilization of the arthrodesis.

POSTOPERATIVE CARE. After forty-eight to seventy-two hours, the dressing and drain are removed, the wound is redressed, and the stump is wrapped with an elastic bandage. After fourteen days, the skin sutures are removed. At the end of the fourth week, the position of the calcaneus in relation to the tibia and malleoli is assured, and the internal fixation may be removed. The patient should not bear weight upon the stump until the eighth week, at which time a walking cast is applied and allowed to remain until fusion of the ankle is complete and full weight may be supported.

The Vasconcelos Amputation

The Vasconcelos amputation, like the Boyd, is employed when the use of an artificial limb is not anticipated. It involves additional surgical complexities in order to achieve slightly greater length. Its principle is mid-tarsal amputation combined with tibiotalar and subtalar arthrodesis and section of the inferior surface of the calcaneus. This last is done in such a manner that the weight-bearing surface lies parallel to the ground. A long plantar and short dorsal skin flap are used.

TECHNIQUE

The first incision starts on the outside of the foot at a mid-point on the posterior portion of the calcaneus and passes forward horizontally along the mid-portion of that bone to the calcaneocuboid joint. It then curves distally and downward to the sole of the foot where it crosses the mid-metatarsal region. When it reaches the medial aspect of the foot, it swings proximally and upward to the tubercle of the navicular bone. The dorsal incision forms a semicircle distally from this point as it crosses the dorsum of the foot just behind the navicular cuneiform joints to join the lateral incision just behind the calcaneocuboid joint. The incisions are carried to bone, and the flaps reflected upward. The mid-tarsal joint is disarticulated, and the distal portion of the foot removed. The tibiotalar and subtalar joints are now denuded of their articular cartilage and prepared for arthrodesis, the distal portions of the neck of the talus and of the calcaneus are removed so that a smooth, even contour is presented where the mid-tarsal joint once lay. Through the lateral limb of the incision, the inferior portion of the calcaneus is removed horizontally, from its posterior aspect to the inferior aspect of the calcaneocuboid joint. The bony surfaces are now placed in position for arthrodesis. The skin flaps are approximated by interrupted sutures, and a drain is instilled in the wound. A plaster cast is used to maintain the position of the arthrodesis. Postoperative immobilization is maintained for sixty to ninety days, or until fusion is complete.

Pirogoff Amputation

The Pirogoff amputation is based on the principle of arthrodesis of the tibia to the calcaneus after the latter has been rotated forward and upward 90 degrees, the rotation is accomplished after section of the calcaneus in the frontal plane in its mid-point. Variations consist of resection of more bone, and slighter degree of rotation of the calcaneus. Although this amputation is said to afford an excellent weight-bearing stump, it has never been popular in this country due to the difficulty in fitting a prosthesis following it. It is included in this discussion for the sake of completeness.

TECHNIQUE

1 *The incision* starts at the tip of the external malleolus, passes upward and medially to cross the anterior aspect of the ankle joint at the level of the distal anterior margin of the tibia, incising the anterior capsule of the ankle joint as it does so It then passes downward and medially to a point one fingerbreadth below the medial malleolus From this point the inferior limb of the incision passes downward at right angles to the bottom of the foot, and is carried across the plantar skin of the heel to reach the tip of the external malleolus The skin incision is deepened to bone by section of all soft tissues

PIROGOFF AMPUTATION

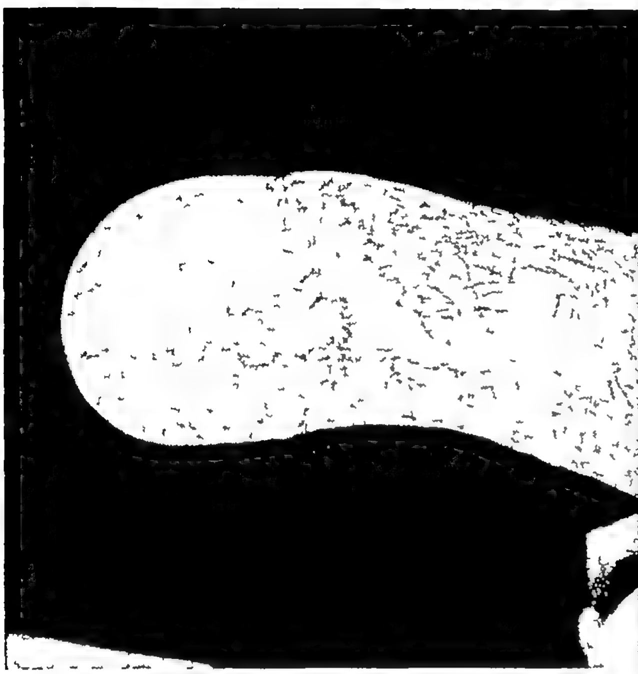

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Fig 228—Pirogoff amputation stump (Walter Reed General Hospital Neg No 4434 A3)

Fig 229—Unsatisfactory Pirogoff amputation X-ray shows posterior dislocation of the calcaneous on the tibia at the site of arthrodesis (Walter Reed General Hospital Neg No 4434 A4.)

2 *Removal of the tarsus* The knife blade is placed in the interval between the external malleolus and talus and drawn downward close to bone, severing the lateral ligaments The knife is then placed between the talus and medial malleolus and brought downward, severing the deltoid ligament The foot is brought into strong plantar flexion, and further division of the capsule and ligaments of the ankle joint is carried out by sharp dissection close to the bone The exposure is carried to a point approximately one-half inch posterior to the posterior margin of the articular surface of the talus Inferiorly, the soft tissue is then dissected free from the posterior aspect of the calcaneus to the level of the attachment of the short flexor muscles to the calcaneal tubercles The calcaneus is now sectioned at a point midway between its posterior articular surface and the tendo Achillis, on a line at right angles with the sole of the foot The tarsus can now be completely removed

3 *Preparation for arthrodesis* The ankle joint at the lower end of the tibia is now exposed by sharp dissection The malleoli are exposed by extra-

periosteal dissection The posterior aspect of the bone is denuded of its soft tissue, care being taken not to damage the tibial artery and vein which pass close behind this bone At a point one inch above the distal end of the tibia, a circular incision is made through the periosteum The tibia and fibula are sectioned immediately below this level The heel flap, containing the calcaneus, is now rotated 90 degrees so that the raw surface of the calcaneus is approximated to the end of the tibia The tibial vessels are doubly ligated at the margin of the posterior flap, the tibial nerve is sectioned, and allowed to fall above the bone level of the tibia, hemostasis is secured The anterior and posterior skin flaps are now approximated and fixed with interrupted skin sutures The calcaneus is held in position by sutures placed through the soft tissues

Lisfranc Amputation

The Lisfranc amputation is a disarticulation of the foot through the tarsometatarsal joint When severance is carried out at this level, the stump falls into a moderate equinus deformity to a point where the anterior tarsus gains contact with the ground There will be no axial deformity as long as the muscle pull on either side of the stump remains in balance When the circumstances are such as this, the Lisfranc amputation results in a satisfactory stump from the standpoint of function In the usual case, however, muscle balance is disturbed to such a degree that equinus is marked, and there appears, in addition, an inversion deformity The division of the distal attachments of the peroneus longus and brevis to the bases of the first and fifth metatarsal bones respectively results in the loss of effective eversion of the foot, and allows the unopposed action of the tibialis anticus and posticus, whose tarsal insertions remain undisturbed, to draw the foot into inversion The tibialis anticus, as the sole remaining dorsiflexor, is overbalanced by the combined strength of the tibialis posticus and gastrocnemius-soleus, and equinus frequently follows If an inversion equinus deformity occurs, the patient will walk on the outer border of the foot, a position which is both awkward and painful

Technique

Long plantar and short dorsal skin flaps are used The plantar incision starts at the mid-point on the inner border of the foot over the first cuneiform bone, and swings in a gentle arc downward medially, crosses beneath the metatarsal heads, and passes upward to the base of the fifth metatarsal bone The dorsal incision starts at this point and crosses the top of the foot, with a very slight convexity, just below the tarsometatarsal joint to join the plantar incision over the first cuneiform bone The incisions are carried to bone, and the flaps are reflected upward The foot is now disarticulated at the tarsometatarsal joint, and the distal portion is discarded All excess plantar muscle is dissected from the flap The nerves are identified and sectioned, and the blood vessels are divided and ligated The peroneal tendons are anchored at the cuboid bone in the line of their normal pull The flexors and extensors of the toes are sutured either to each other, or to the end of the stump The skin flaps are then approximated and any excess tissue is removed The wound is closed with interrupted sutures, and a dry dressing and compression are applied A drain is not used Stitches are removed on the tenth to twelfth postoperative day

Obsolete Amputations

There are several obsolete amputations of the tarsus which deserve mention because of their constant recurrence in the literature

Chopart amputation, or amputation through the mid-tarsal joint is not a good amputation for it almost invariably results in a painful deformed stump

which is incapable of satisfactory weight-bearing The severe equinus deformity which usually follows this procedure is based on the alteration of the mechanics of the foot, following division of the muscles to the forefoot and the creation of new force pathways When amputation is carried out at the level of the mid-tarsal joint, there is a loss of the attachment of all major muscles which insert below the ankle joint, with the exception of the gastrocnemius-soleus The unopposed action of this muscle group results in equinus deformity Even more important than this factor is the derangement of the force pathways The posterior portion of the calcaneus remains as the only normal weight-bearing surface of the foot Its anterior portion, which is elevated to form part of the arch in the normal foot, is deprived of its supporting structures and is readily depressed by the superincumbent body weight acting through the talus, until its entire lower surface is levered downward to the ground The subsequent changes are

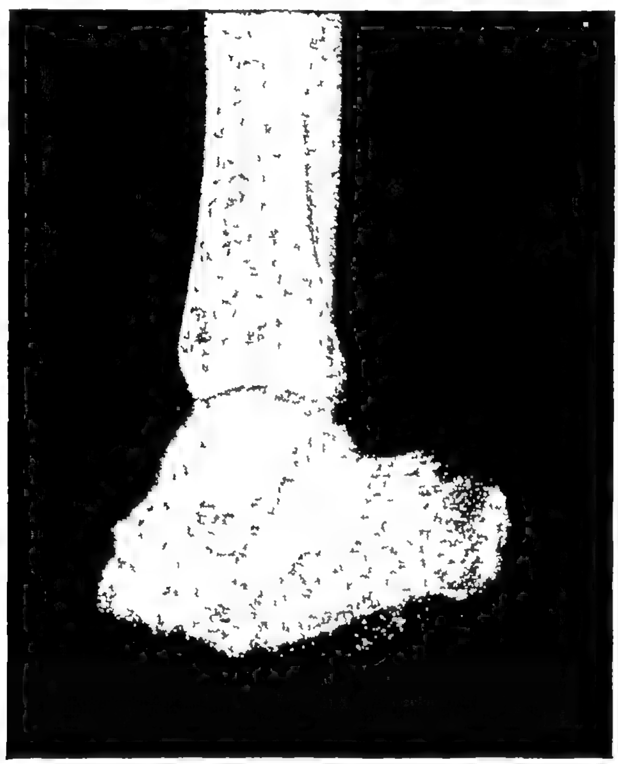


Fig 230 —Deformity typical of amputation at, or near, the mid tarsal joint

similar to those occurring in paralytic flat foot The talus, which is firmly fixed in the ankle mortise, acts through the subtalar joint to force the calcaneus into marked valgus while it drops downward, forward, and inward until it is in contact with the ground The anterior aspect of the calcaneus, which now lies behind the center of gravity, acts as the center of rotation for further downward displacement of the talus, this proceeds until the anterior articular surface of the calcaneus is in contact with the ground, and the calcaneus is in extreme equinus The final result is a weight-bearing surface which is formed by the articular surface of the head of the talus and by the small area in the anterior-inferior portion of the calcaneus This position is unsatisfactory for weight-bearing for two reasons (1) the contact area is small, and in such a position that it throws strain on the subastragaloid and ankle joints, and (2) it places the scar on a weight-bearing surface where it is subject to constant trauma leading to eventual breakdown

To combat the equinus deformity in Chopart's amputation, two procedures have been devised, both of which have been proved inefficient. The first of these is lengthening of the tendo Achillis. Since this corrects only one of the deforming forces, it is obvious that it can be of only temporary benefit. The second procedure is a system of muscular suspension at the anterior aspect of the calcaneus and talus which utilizes all the strong muscles of the foot to counteract the pull of the tendo Achillis and the lever action on the calcaneus. This procedure is so rarely successful that it is not recommended.

TECHNIQUE

1. *Skin incision.* The dorsal incision starts at a point overlying the tubercle of the navicular bone and is carried across the dorsum of the foot at the level of the mid-tarsal joint to the lower border of the cuboid bone. The plantar incision then curves downward to the sole of the foot, crosses the mid-shafts of all metatarsal bones, and rises to join the dorsal incision at its point of origin. The skin incision is deepened to bone, and the flaps are dissected free to the level immediately above the mid-tarsal joint.

2. *Disarticulation of the forefoot* is accomplished by severance of the capsule and ligaments of the mid-tarsal joint. The ligaments should be cut under tension. Those on the anterior surface are sectioned with the foot forced into strong plantar flexion, those on the posterior surface are sectioned with the foot in dorsiflexion.

3. *The posterior flap* is now débrided of all excess ligamentous and muscular tissue. The plantar vessels are identified and ligated at a point immediately above the end of the flap. The medial and lateral plantar nerves are dissected from the neurovascular bundles and sectioned. The extensor tendon, the tibialis anticus, the common extensor, and the peroneus tertius are sutured to bone in the line of their normal pull to counteract the action of the tendo Achillis which forces the foot into equinus.

4. *The tourniquet* is removed, and hemostasis is secured.

5. *The plantar flap* is approximated to the dorsal flap and fixed with interrupted skin sutures. A drain is instilled near the lateral margin of the wound, and dry dressings are applied. Elastic bandage compression is utilized in such a manner that it counteracts the tendency to equinus in the stump. A plaster cast is not used, for it cannot be applied effectively for this purpose.

Sedillot's amputation is a variation of the Pirogoff in which a posterior oblique osteotomy of the tibia is done in such a manner that it will match an oblique osteotomy of the calcaneus after the removal of the remainder of the tarsal bones. The normal weight-bearing surface of the sole of the foot covers the end of the stump. This amputation has been discarded because of its technical difficulty, frequent failure of bony fusion, difficulty in fitting a prosthesis, and the fact that its functional result is no better than that of the simpler procedures.

Ricard's amputation consists of mid-tarsal amputation in combination with astragalectomy. It is designed for weight-bearing on normal plantar skin with tibial-calcaneal motion. It has been proved worthless because of the high incidence of pain, deformity, and arthritic change.

Malgaine's amputation is an attempt to utilize the inferior surface of the talus as the weight-bearing point after the removal of the calcaneus. This results in a stump which is painful and generally unsatisfactory under pressure.

Mid-tarsal amputation in combination with *subtalar* arthrodesis is unsatisfactory because of the resultant equinus deformity.

AMPUTATION THROUGH THE LOWER THIRD OF THE LEG

Severance through in the lower third of the leg is unsatisfactory as a site for final amputation because of the poor nutrition of the soft tissues and the unsatisfactory adaptation of the stump to a prosthesis The blood supply to both skin and subcutaneous tissues in this area is scant, and underlying structures are largely fascial and tendinous This circulatory inadequacy is accentuated in amputation and is responsible for the frequent occurrence of breakdown of the primary amputation, as well as for the cold, cyanotic, ulcerating stump commonly found in late cases The occasional stump which is satisfactory from the surgeon's viewpoint is unfortunately subject to certain prosthetic objections The long lever arm is of no functional advantage in activating the prosthesis Its constant up and down motion (piston action) during walking causes friction and frequently results in breakdown at the suture line In addition, it extends so far into the shin piece of the artificial limb that it cannot be fitted by the usual well-formed lower leg and ankle prosthesis but must, instead, be accommodated by a larger one which resembles an inverted milk bottle in appearance This is most unsightly, and is difficult to fit

AMPUTATION THROUGH THE MIDDLE THIRD OF THE LEG

The ideal below-knee amputation falls within the middle third of the leg The basic criteria of success in this procedure is the patient's ability to wear a prosthesis comfortably and to use it effectively To understand the requirements of surgery, it is necessary to have some knowledge of the artificial limb, to appreciate the qualities of the ideal stump, and to comprehend the principles which make, of these two elements, one smoothly functioning unit

First of all, it must be understood that weight is carried on the expanded metaphyseal flare of the upper end of the tibia and *not* on the end of the stump This fact influences the shape of the stump and the arrangement of the padding upon it It is not necessary to create a thick weight-bearing pad about the end of the stump In fact, this is definitely contraindicated, for bulky, redundant soft tissue masses fit poorly in a prosthesis and are frequently subject to circulatory changes which result in edema, congestion, and eventual breakdown of the end of the stump, nor should there be any superfluous skin or masses of tissue anywhere The stump should be rounded and gently tapering, with no protrusion of the bone beyond its protective side covering of muscle Though the distal end of the tibia does not bear weight, its anterior aspect does come in contact with the socket of the prosthesis every time the leg is placed in extension It will require no bulky padding however, if it is beveled and smoothed to a point where no sharp, projecting bony corners are present

Since the weight is carried on the metaphyseal flare, it is desirable to have the scar well removed from that area Ideally it should be transverse, and should fall approximately one fingerbreadth behind the posterior margin of the tibia If it lies one and one-half inches or more above that point, it is under tension when the prosthesis is worn because of the upward pull of the proximal end of the socket, and it may also be subject to direct pressure from the back of the socket The exact location of the suture line depends upon the proportionate length of the two skin flaps The concepts on this point have undergone revision in recent years There is universal agreement on the fact that the suture line should fall behind the tibia, the question is, "How far?" To show the difference of opinion of various authorities Vasconcelos feels that a long anterior and short posterior flap in the ratio of 3 1 should be used, Kirk prefers the long anterior flap in the ratio of 3 2, Lemesurier recommends an anterior

flap which is one inch longer than the posterior, Carnes prefers an anterior flap one centimeter longer than the posterior, Morris and Alldredge each recommend flaps of equal length, Holscher simply cuts the flaps too long, and trims them to lie immediately behind the bone at the conclusion of the operation. His special technique for accomplishing this is an excellent one, especially for the surgeon who amputates only occasionally and has difficulty in accurately determining the length of the flaps. The writer recommends the method of Carnes for the experienced amputation surgeon and the method of Holscher to those who perform amputation infrequently. These are described in the discussion of techniques which is to follow. No matter what the method employed to form the skin flaps, the skin itself should be soft, pliable, and free from edema, the surgical scar should be nonadherent, and the deeper tissues should be free from pain on pressure.

The exact length of the stump is another consideration, and it, too, is based on functional coordination of the stump with the prosthesis. Six inches of bone length is sufficient to control the artificial limb effectively. There has been some confusion as to the standard of measurement. This has arisen because of the development of two systems, one of which has as its basis actual bone length, and the other the functional length of the stump within the prosthesis. Actual bone length is measured from the anterior-medial aspect of the tibial plateau, adjacent to the patellar tendon, to the bone end. Functional stump length is measured from the point of insertion of the medial hamstring tendon to the end of the bone when the knee is flexed. In the present discussion, actual bone length is used since it is less confusing to most individuals and is facilitated by the easy identification of bony landmarks. The ideal bone length in below-knee amputations is six inches. This is not a hard-and-fast rule, it may vary between five and seven inches in very tall and very short individuals. This length provides an excellent lever arm. Longer stumps are no more effective from the standpoint of power or control and are subject to prosthetic and circulatory objections. On the other hand, shorter stumps lose their efficiency progressively with loss of length, the very short stump will tend to fall out of the socket of the prosthesis. In determining the length of the stump within the ideal range, consideration must be given to the adequacy of available skin. This tissue must be sufficient to cover the bone end without undue tension being placed upon the suture line during the up-and-down excursion of the stump within the prosthesis.

In the below-knee stump of normal length, the presence of the fibula is a distinct functional advantage. Because of it, the shape of the stump is triangular in cross section, rather than circular, and this prevents the prosthesis from rotating. There is, between it and the tibia, a certain amount of spring action which adds resilience to the stump and cushions any pressure upon it from the prosthesis. Its projecting bony surface makes adjustment of the artificial limb somewhat difficult, but its spring action and the additional control which it gives far outweigh that technicality in favor of its retention. In order to facilitate the fit of the prosthesis as much as possible, the fibula is sectioned one and one-quarter inches higher than the tibia, so that the end of the stump may be tapering and not needlessly bulky. The inexperienced surgeon may consider its complete excision in hopes of obtaining additional skin for wound closure, this is poor procedure, for only a minimal amount of skin can be gained in this manner, and the functional presence of the fibula is lost. In spite of the desirability of retaining this bone, however, there are some instances in which its removal is indicated. One is excessive, painful mobility, and another is chronic bursitis. Painful mobility of this bone is due to the loss of the normal support of the interosseous membrane and other soft structures, and the constant motion

within the prosthesis. Although arthritis of the proximal tibiofibular joint is an occasional source of trouble, the pull on the soft tissues and the pressure of the prosthesis on the mobile, abducted fibula are the principal causes for concern. The shorter the fibula, the greater is its tendency to develop this condition. The bursa overlying the subcutaneous surface of the fibula may become inflamed through the constant friction and pressure of the prosthesis. If any such irritation is noted, the artificial limb should be checked, and adjusted immediately, for if the situation is not alleviated, a chronic bursitis may result, the lining of the sac may become permanently thickened and edematous, the bursa may be subject to constant or intermittent swelling, the overlying skin may become avascular and dull red in color, and, in the extreme case, tissue breakdown may occur. Whenever such a bursitis cannot be controlled conservatively, the entire underlying bone should be removed. Fortunately, when removal of the fibula becomes necessary, its loss can be compensated for to some extent by adjustments in the socket and corset of the prosthesis.

In the short below-knee stump, the situation is different, and the fibula should be routinely excised. Such a stump does not afford a perfect lever arm, and its fit within the prosthesis is highly important. Experience has demonstrated that fit is far more satisfactory, and the incidence of secondary breakdown, painful stump, and bursal formation is decidedly less frequent when the fibula is removed. Great care must be exercised during surgery to ensure that the scar required will not lie where it will receive pressure from the weight-bearing portion of the prosthesis. The fibula can usually be removed from below through the open end of the wound during surgery.

A few points should be made in regard to the surgery involved in removing the fibula. (1) When this procedure is carried out at the time of final amputation, or subsequent to it, it is always performed in a clean field. Consequently, no concern need be felt when the tibiofibular joint connects with the knee, as it does in some instances, for there is little danger of infection later involving the knee joint. Modern aseptic technique, and the use of penicillin and other chemotherapeutic agents are further safeguards. (2) Whether partial or complete removal of the fibula is to be performed, the question arises: Should the bone be excised intraperiosteally or extraperiosteally? In intraperiosteal removal, there is often some regeneration of periosteal new bone which usually is palpable at the end of the stump. In extraperiosteal removal of the bone, the bleeding from the veins about the periosteum and intermuscular septum is difficult to control. From the practical point of view, it does not seem to make much difference which method is used as long as the prosthesis is well fitted. The writer has adopted the practice of removing the fibula or part of it intraperiosteally. This affords a satisfactory exposure of the periosteum, the bleeding points may be clearly seen and controlled under direct vision. (3) If the fibula is being resected at the time of amputation, as it is routinely in the short stump, its removal may be carried out through the open wound, but if it is indicated after the wound is closed, it may be excised through a lateral longitudinal incision starting not less than one and a half inches distal to the proximal pole. This placement of the scar allows it to fall away from pressure areas.

Synostosis between the distal ends of the tibia and fibula is sometimes carried out with the mistaken idea of forming a broader and more stable stump end upon which to bear weight. Since, as has been noted above, the below-knee stump is not end-bearing, it follows that such a procedure would be entirely unwarranted on that basis. It is true, however, that it does stabilize the tibia and the fibula throughout their entire length, and, for this reason, it is sometimes

used as an alternate procedure to removal of the fibula when there is excessive painful mobility of that bone. The length of postoperative convalescence after synostosis far exceeds that following resection, and this is an undesirable feature. There is one decided objection to the use of this step routinely, and that is that it destroys the spring action of the fibula which is so beneficial in lessening the friction of the stump within the prosthesis.

It is common knowledge that, following amputation through the leg in children, the fibula will frequently overgrow the tibia to such an extent that it will protrude well beyond it. Both synostosis and excision of the upper fibular epiphysis have been recommended to control that excessive growth. However, the plastic nature of the bones during the growth period usually causes the fibula to fall toward the mid-axis of the stump, where it adds valuable functional bone length. Since the rate of growth of the tibia and fibula under the varying conditions of amputation in children is difficult to establish, I feel that it is better to refrain from any surgical interference with the fibula at the time of amputation, other than the routine one and one-quarter inch shortening, and to resect its distal end at a later date if it interferes with function.

Surgical Techniques of Amputation Through the Middle Third of the Leg

Final amputations through the middle third of the leg are definitive plastic procedures and require careful attention to detail if a functional stump is to be obtained. There are a number of techniques which may be employed at this level, only three of which will be described here. Each, if performed with care, results in a satisfactory below-knee stump.

The Method of Carnes

Position of the patient—supine

Operative Plan

The anterior skin flap is slightly longer than the posterior. With the exception of the skin, each tissue is treated as it is encountered from the anterior to the posterior aspect of the leg. The principal feature is the fact that the position of the surgeon and of the limb need not be changed frequently, for each step can be performed in full vision from above.

Technique

1. *The Measurement of the Skin Flaps*

The diameter of the leg is measured at the desired bone level. It will represent the amount of skin required to cover the end of the stump. The leg should not be compressed by resting on the amputation block, or a false reading will be obtained.

The anterior flap should be 1.0 cm. longer than the posterior. Therefore, add 0.5 cm. to the radius (½ diameter) of the leg for the length of the anterior flap, and subtract 0.5 cm. from the radius for the length of the posterior flap.

The length of each flap below the bone level is now marked by a small nick in the skin.

2. *Skin Incision*

The anterior flap is "tongue-shaped" rather than semicircular. The incision starts at the bone level at the mid-point of the medial aspect of the leg and swings convexly downward, through the site previously marked, and thence upward to the mid-point of the lateral aspect at the same level as the point of origin. As it crosses the tibial crest at the most distal end of the flap, it is carried deep through the periosteum in order to establish a marker for future

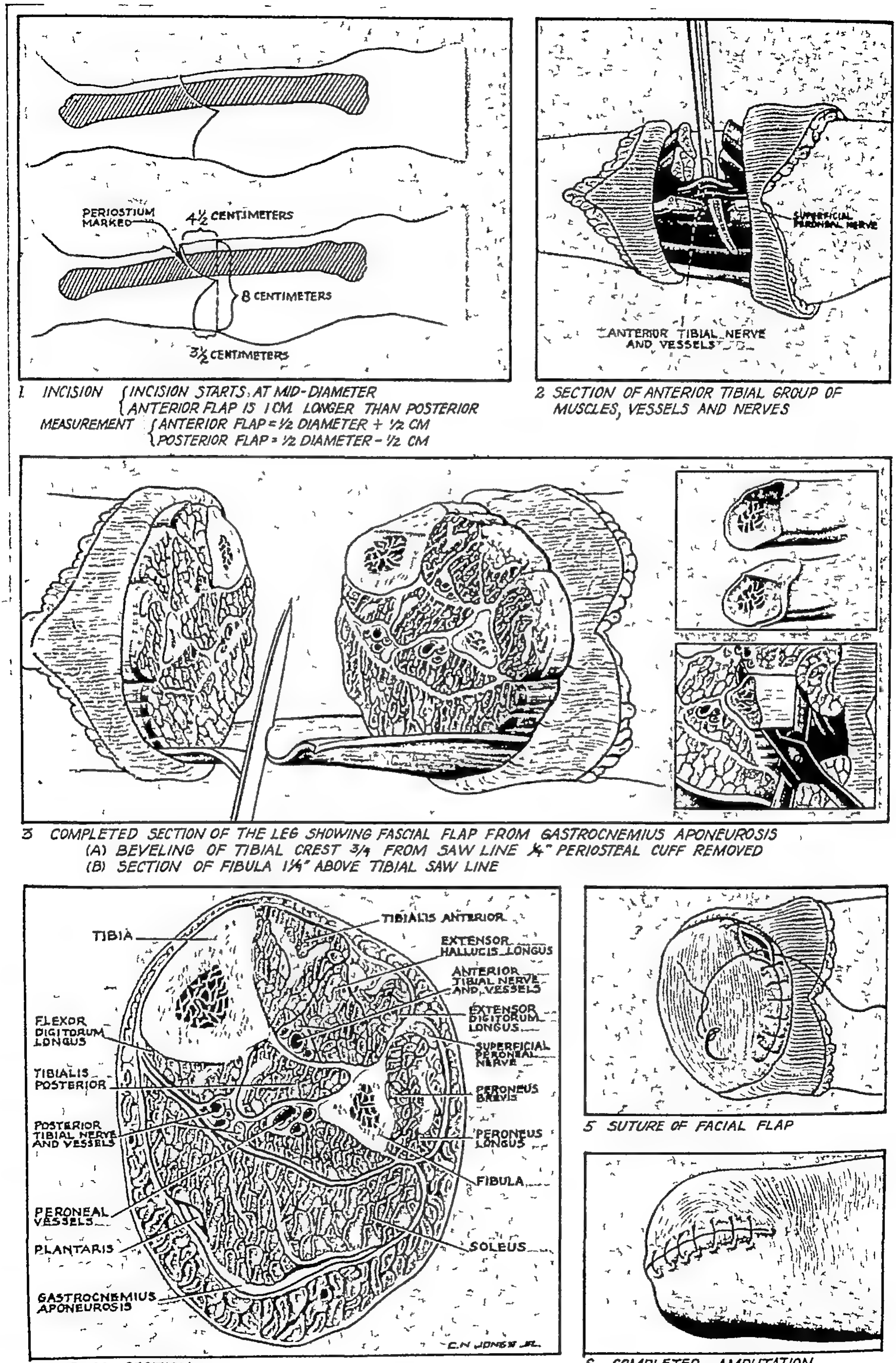


Fig 231 —Below knee amputation

measurement. The posterior flap is semicircular. It connects the two ends of the anterior incision and passes through the skin marker on the posterior aspect. Both of the incisions are carried to muscle fascia and reflected upward to the bone level by sharp dissection. The anterior flap can be freed with ease, but the posterior flap is usually bound down in its central portion by a dense band of fascia extending from skin to muscle. This band contains the sural vein and nerves. The vein should be cut and tied and the nerves drawn down and sectioned at this time.

3 *Re-establishment of the Bone Level*

Because of its retraction, the skin flap cannot be used as a satisfactory measuring stick to determine the saw level. Instead, the original length of the flap is measured off on the bone from the nick made in its anterior surface at the time of the incision, and a small saw cut is made. The periosteum is incised at the level of this saw cut and stripped downward to allow transverse section of the bone and beveling of the tibial crest.

4 *Section of the Structures in the Anterior Compartment of the Leg*

A curved hemostat is slipped into the natural cleavage plane at the lateral aspect of the tibia and allowed to follow along the interosseous membrane and pass over the anterior aspect of the fibula to emerge just anterior to the peroneus brevis. The superficial peroneal nerve is identified as it lies in the fat in the interval between the extensor digitorum longus and the peroneus brevis. It is drawn down gently, sectioned, and allowed to retract. The muscles are then sectioned at a site one-fourth of an inch distal to the saw level so that they will lie flush with it after retraction. As the muscle section nears completion, special care is taken that the anterior tibial vessels and nerves are identified. These vessels are isolated, sectioned, and doubly ligated, the nerves are drawn downward, sectioned, and allowed to fall upward in their beds.

5 *Bone Section*

The crest of the tibia is beveled before transverse section of the bone. The saw is placed at a point one-half to three-quarters of an inch above the bone level and is carried obliquely distalward to cross the bone level three-sixteenths of an inch anterior to the marrow cavity. The tibia and fibula are divided transversely at the same level. They are then grasped by a bone-holding forceps just below the saw line, and pulled anteriorly and distally to expose the posterior muscles of the calf.

6 *Section of the Posterior Muscles*

A large amputation knife is used to divide the posterior muscles, starting at a point one-quarter inch distal to the bone end and passing in a posterior and slightly proximal direction until it reaches the gastrocnemius aponeurosis. It is then drawn downward parallel to the fibers of this structure until a fascial flap is formed sufficient in length to cover the end of the stump. The gastrocnemius aponeurosis is then divided transversely. During the process of muscle section, the dissection is carried out slowly so that the posterior tibial nerve can be drawn down and sectioned, and the posterior tibial vessels can be identified and ligated as they are encountered. The severance of the distal portion of the limb is now complete.

7 *Excision of the Fibula*

The fibula is now exposed subperiosteally from below to a point one and one-quarter inches above the end of the tibia, where it is divided with a Gigli saw or bone-biting forceps. The distal piece is removed, giving wide exposure

Fig 232

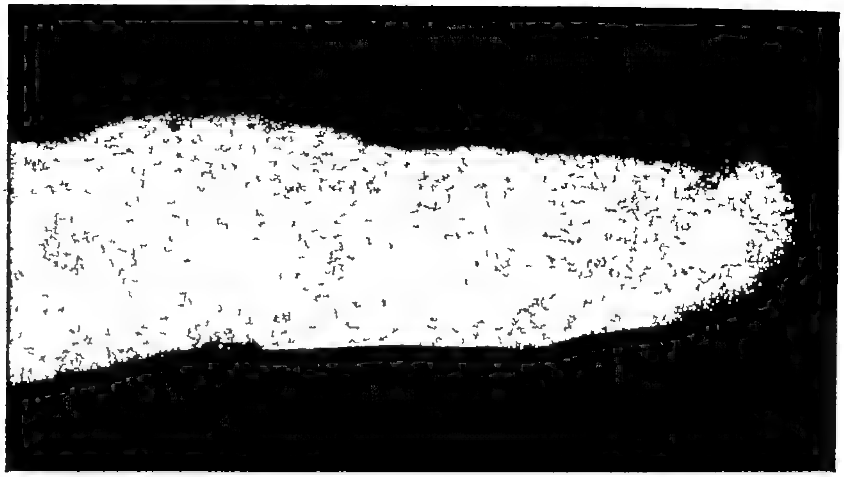


Fig 233

Figs 232 and 233—The method of Carnes (Walter Reed General Hospital Neg No 4919 2,1)

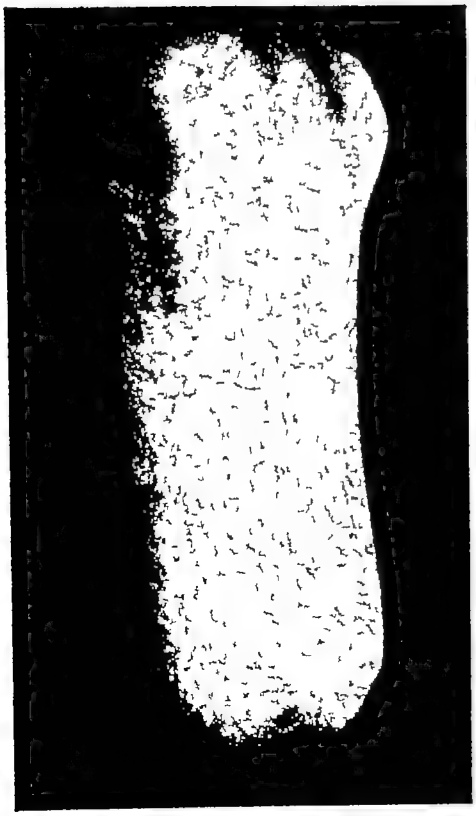


Fig 234

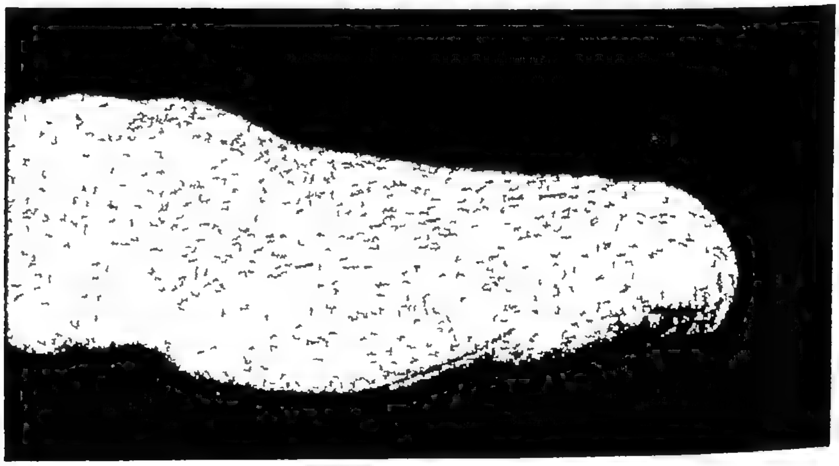
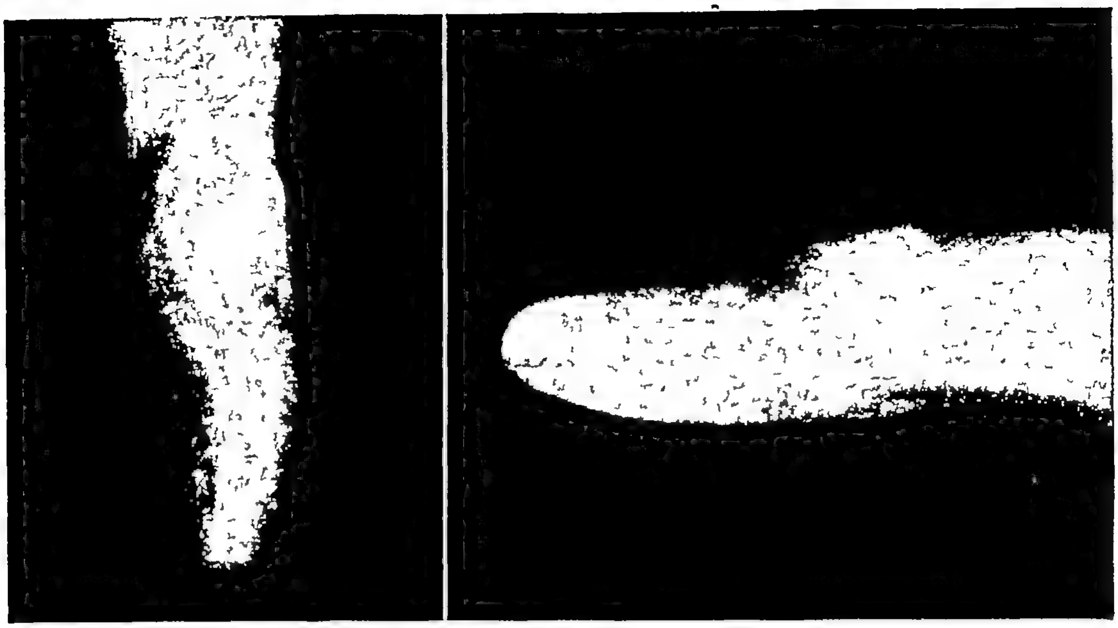


Fig 235

Figs 234 and 235—The method of Kirk (Walter Reed General Hospital Neg No 4962 3,2)



236 237

Figs 236 and 237—The method of Holscher and Warner (Lawson General Hospital Neg No 1441)

to the periosteal sleeve which remains This is dissected free under clear vision, and the troublesome bleeding controlled as it is encountered The ends of the tibia and fibula are smoothed with a bone file, and all bone dust is washed away with normal saline

8 *Closure*

The tourniquet is removed and hemostasis secured The gastrocnemius fascia is brought forward over the end of the stump and fixed with plain catgut sutures to the anterior muscle fascia and periosteum If there is any bulky muscle, a medial or lateral muscle wedge may be removed before suture of the fascia The skin flaps are approximated and fixed with interrupted skin sutures, and a drain is instilled in the medial or the lateral aspect of the wound Dry dressings are applied, the sides of the tibial crest are padded against pressure, and an elastic bandage is wrapped from stump end to above the knee This is covered with sheet wadding, and a posterior plaster splint is applied from mid-thigh to the anterior margin of the stump end to provide immobilization, tissue rest, and protection from external trauma The drain is removed in from forty-eight to seventy-two hours The patient should be kept at bed rest with the leg elevated until the fourteenth day, at which time the stitches are removed Some surgeons prefer not to cover the end of the muscle with fascia If that is the case, the fascia may be sectioned along with the posterior calf group muscles I have done many cases in this fashion, but on review of the long range end results, I feel that the fascial covering is superior, since it groups the muscles about the end of the bone and prevents their retraction

The Tendoplastic Method of Kirk

Position of the patient—Supine

Operative Plan

This amputation utilizes a long anterior and a short posterior flap in the ratio of 3 2 The gastrocnemius aponeurosis is employed as a covering for the end of the bone and the cut end of the muscles Kirk stresses the fact that the

stump should be measured from the insertion of the internal hamstring since only the portion distal to this can be contained in the socket of the prosthesis

Technique

1 *Skin Incision*

The anterior incision begins halfway between the anterior and the posterior aspect of the leg on the medial side just above the intended saw line It passes distally, laterally, then proximally to the mid-portion of the lateral aspect of the leg at the same level as the point of origin The posterior flap is cut in a similar manner The anterior flap is now dissected to a point just above the saw line The posterior flap is dissected proximally for about one-half inch The posterior skin distal to the incision is cut away for a distance of two to three inches to expose the gastrocnemius aponeurosis

2 *Muscle Section*

The anterior tibial muscle group and its fascial covering are cut transversely about one-half inch below the intended saw line in order that, when retracted, they will lie at the bone level The calf muscles are transfixed just behind the tibia and fibula, at the saw line, by a long-bladed amputation knife, which is then drawn posteriorly and distally through the posterior or posterior-lateral muscle group to form a triangular-shaped flap of muscle, tendon and fascia, sufficiently long to cover the end of the stump

3 *Bone Section*

The periosteum is cut circumferentially one-fourth inch above the intended saw line except over the tibial crest where it swings upward for one-half inch to allow for beveling of that bone The muscles about the fibula are dissected free for a distance of one inch The tibial crest is beveled from a point one-half inch above its intended section The tibia is now sectioned at right angles to the long axis of the leg The fibula is sawed through by means of a Gigli saw at a level one inch above that of the tibia The cut surface of both bones is smoothed with a file to eliminate all sharp corners

4 *The Preparation of a Posterior Muscle Flap*

The posterior muscle flap is trimmed by cutting away muscle substance from its anterior aspect so that it will not be more than one-fourth inch thick at its base and one-eighth inch thick at its apex A test fit is made by approximating the flap to the anterior muscle fascia and the periosteum on the medial aspect of the tibia Any excess tissue is trimmed away

5 *Closure*

The anterior tibial, posterior tibial, and peroneal arteries are isolated and doubly ligated All other large vessels are ligated The nerves are isolated drawn down, sectioned, and allowed to fall upward in their beds The tourniquet is now released, and hemostasis is secured The posterior myotendinous fascial flap is now brought over the end of the stump and sutured to the periosteum on the medial aspect of the tibia, and to the anterior muscle fascia on the lateral aspect of the leg by interrupted catgut sutures All bone and cut muscle are covered The skin flaps are approximated by interrupted skin sutures A drain is inserted near the end of the incision, passing under the fascial flap The wound is covered by sterile gauze dressing and fixed by elastic bandage compression, extending from the end of the stump to above the knee The knee is fixed in extension by a posterior, well-padded board splint, extending from the upper third of the thigh to the stump end Drains are removed at the end of forty-eight hours Sutures are removed at the end of fourteen days

The Posterior Approach of Holscher and Warner

Position of the patient—prone (face down), with the knee flexed

Operative Plan

Anterior and posterior skin flaps are cut extra long at the time of the incision and are tailored to be of equal length when final closure is effected Terminal muscle beveling and lateral muscle wedges are employed to eliminate redundancy of the stump, and a posterior fascial flap is made from the gastrocnemius aponeurosis to cover the bone end beneath the skin flaps The posterior approach is utilized

Technique

1 *Skin Incision*

The anterior incision starts at a mid-point on the lateral aspect approximately one and one-half inches above the intended tibial level, progresses distally

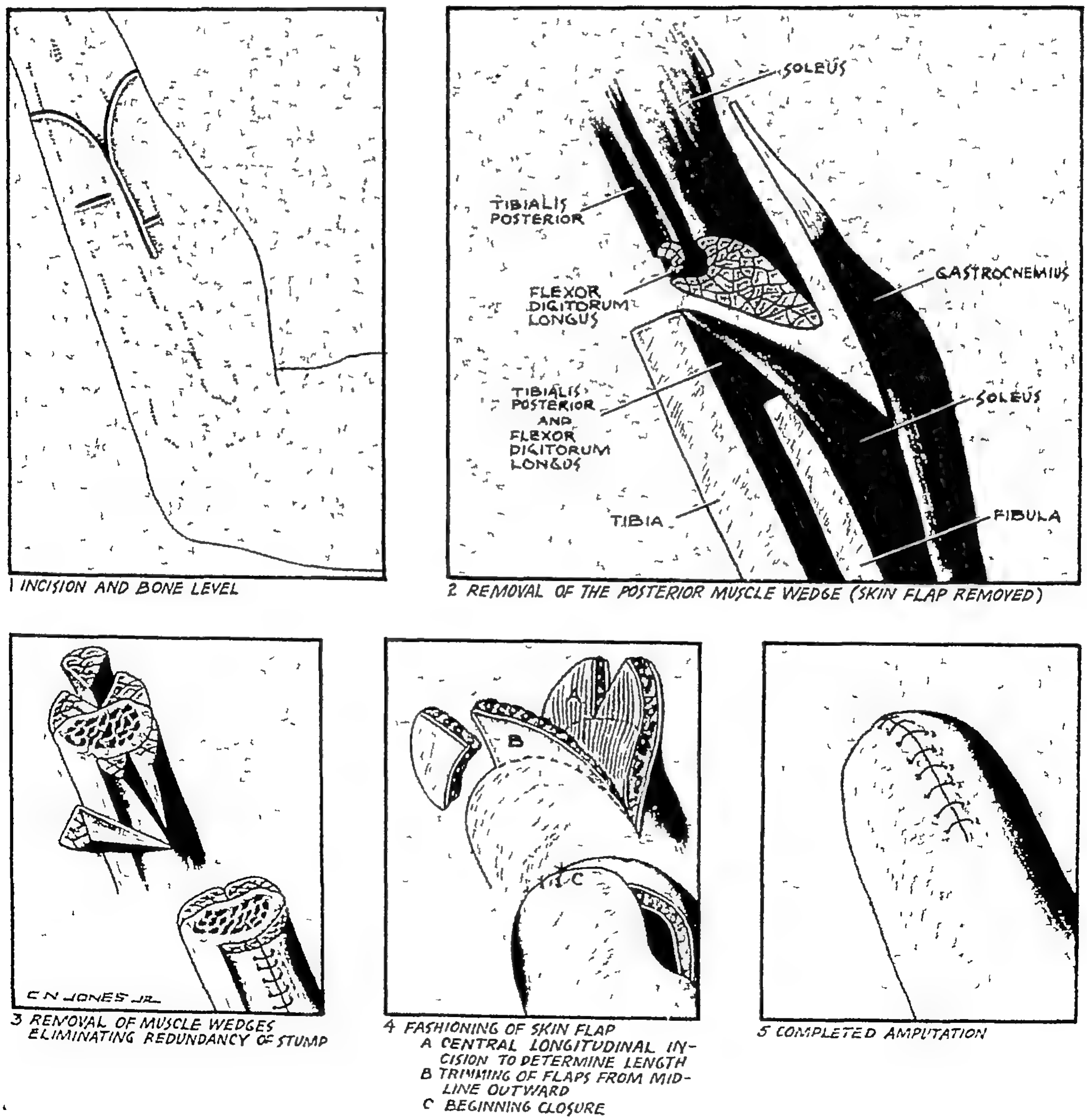


Fig 238—Below knee amputation after the method of Holscher and Warner

beyond that site, then swings in a gentle distal arc to the medial aspect, and thence proximally to a site level with the point of origin. The posterior incision branches off from the anterior one just distal to the proposed level of the tibia, and follows a similar curve, rejoining the anterior incision on its opposite aspect. It is preferable to err on the side of too great length in the formation of the flaps, for final tailoring will dispose of any excess, and there will be no danger of a too tense closure. The flaps are undermined and reflected upward only as far as is necessary to allow freedom in subsequent steps. They may both contain superficial fascia, but the anterior flap should not carry the deep fascia.

2. *Osteotomy*

The anterior deep fascia, the tibial periosteum, and the anterior muscle group are first incised en masse at a point six to eight inches distal to the tibial plateau. (This may be found by palpating the space between the bones, antero-mesially, at the flexed knee.) The tibia and fibula are then sectioned squarely at that level.

3. *Myotendoplasty*

Immediately after osteotomy, the amputation knife is inserted behind both bones at the saw-cut level, and drawn through the posterior muscle group obliquely to resect it at a point sufficiently distal to allow for a tendinous gastrocnemius flap long enough to close over the bone end. (As with the skin, it is well to cut this flap of liberal length, as it can be adjusted at the time of closure.) The fascial flap, with its investing skin, is reflected upward, exposing the soleus, tibialis posticus, and flexor digitorum longus. These are skived out by placing the amputation knife on the posterior aspect about three inches proximal to the saw line, and drawing it anteriorly and distally to the terminal posterior tibial margin. For the sake of terminal tibial circulation, care should be taken, during the beveling process, to avoid detaching from the tibial periosteum the muscle substance which contains the posterior tibial artery and vein.

4. *Further Treatment of the Tibia and Fibula*

The fibula is re-sectioned about one and one-half inches above the tibial saw level. It is easily accessible and a straight saw can be used. A one-sixteenth inch periosteal cuff is removed from the fibula and the bone edges are filed smooth. The tibial crest is liberally beveled, the saw being drawn from within outward to avoid entrance into the medullary canal. A one-sixteenth inch periosteal cuff is removed from this bone also, and its edges are smoothed with a rasp.

5. *Vessels and Nerves*

The vessels are dissected out, ligated and divided in the usual manner, one to two inches above the saw level. The nerves are identified and sectioned, only the posterior tibial one requiring ligation. The sural nerve should be traced beneath the posterior skin flap and excised, to obviate its inclusion in the cutaneous scar.

6. *Closure*

The closure is effected with the *knee in full extension*. Any muscle on the external surface of the gastrocnemius tendon flap is removed, and the flap is then drawn over the end of the tibia and trimmed to the desired length. The center of its terminal edge is temporarily fastened to the deep fascia immediately above the bevel of the tibial crest. The end of the stump is seen to be gently tapering on its anterior-posterior plane. Generous wedges of fascia and muscle are removed medially and laterally from the gastrocnemius and peronei to eliminate any redundancy on that plane. The stump is now evenly conical in shape. The fascial flap is freed and reflected, the tourniquet is released, and

hemostasis is secured Final suture of the tendinous flap is carried out, affixing it to the anterior fascial covering The skin flaps are brought over the end of the stump, and their ideal length and shape are determined, care should be taken that tension will be equivalent to that of normal skin, the approximation of the flaps should allow the suture line to fall immediately behind the tibia Tailoring of the flaps is done by incising each longitudinally at a central point This incision is carried to the desired level, and from that point the skin is trimmed away medially and laterally to achieve the desired shape of the flap Closure is effected with interrupted suture, and a drain is rarely used The wound is dressed, and a closed circular cast is applied from the groin to the end of the stump with the knee in extension It is well to start the thigh portion of the cast first, contouring it carefully over the supracondylar region to prevent slippage, and using the plaster bandage to mold the stump as its terminus is approached Fewer thicknesses of bandage are placed over the dressing, and compression in that area should be just enough to take up the resilience of the dressing itself Cast and stitches are removed at the end of three weeks

Shrinkage of the Below-Knee Stump by Neurectomy

Adams has recommended neurectomy of the branches of the tibial nerve passing to the two heads of the gastrocnemius as a method of achieving rapid and complete atrophy of the below-knee stump, particularly in well-muscled adults I feel that such a surgical procedure is necessary only in the occasional case, for proper shrinkage will usually take place if adequate bandaging is persistently carried out Aside from the additional surgery which this procedure would entail, I feel that it is undesirable because it places a scar in the popliteal space at a point where it may be subject to pressure from the posterior rim of the socket

Technique

A two and one-half inch posterior longitudinal incision is made, arising in the lower part of the popliteal space and extending down the leg As the medial sural cutaneous nerve is met lying beneath the deep fascia, it is retracted medially The dissection is continued into the popliteal space until the tibial nerve is exposed The branches of this nerve which pass to the two heads of the gastrocnemius muscles are identified and sectioned If the branch to the soleus is within the operative field, it, too, is sectioned Hemostasis is secured Skin and fascia are closed with great care to obtain a minimum of scar

Methods of Correction of Flexion Contracture of the Knee

Flexion contractures of the knee are extremely disabling and may destroy the function of the below-knee stump entirely They usually occur when the knee has been allowed to remain bent for a prolonged period following injury or operation For the most part, those which originate in this manner can be relieved by adequate physiotherapy and the use of the artificial limb Some however, have as their etiology tissue destruction and scar formation These demand surgical measures If the involvement is minor in nature, it may be corrected by the wedged cast and by hamstring lengthening, if the deformity arises from skin affection alone, it may be alleviated by a plastic procedure such as the Z-plasty or skin grafting, but if deep and binding cicatrix has invaded the popliteal region, any surgical approach is usually doomed to failure Experience has proved that massive scar excision and capsulotomy in this area are seldom successful Where such would be required, or in those instances where

contracture is based on marked quadriceps femoris insufficiency, the course to follow is either adaptation of the stump to a bent-knee prosthesis, or reamputation at a higher level

AMPUTATION THROUGH THE UPPER THIRD OF THE LEG

When amputation is carried out through the upper third of the leg, a satisfactory stump can be obtained, but it is not ideal, and its proper fit within the prosthesis is difficult to achieve Weight is borne on the metaphyseal flare, just as in amputation through the middle third of the leg, and the operative plan is predicated upon the same general principles as at that level, but the short stump provides less soft tissue for covering and has a tendency to fall out of the prosthesis In order to create maximal function, there must be certain modifications in the surgical techniques described for the ideal below-knee stump

1 Formation of the Skin Flaps

The skin flaps are fashioned from available tissue, and, consequently, the principle of placing the scar transversely just behind the tibia cannot always be carried out If this is the case, the suture line should be placed at the most distal point possible on the lateral or posterior aspect, it should not be placed on the anterior aspect overlying the tibia, if this can be avoided, for there it will be subject to pressure from the prosthesis, nor should it run from anterior to posterior aspect, for there an infolding of the skin is apt to develop

2 Formation of the Fascial Flap

The fascial covering of the stump end must be obtained from any available source of fascia That from the anterior and lateral aspects of the leg is satisfactory, but, whenever possible, it is preferable to use the posterior muscle fascia of the gastrocnemius (This is above the level of the gastrocnemius aponeurosis utilized in the stump of ideal length)

3 Treatment of the Bone

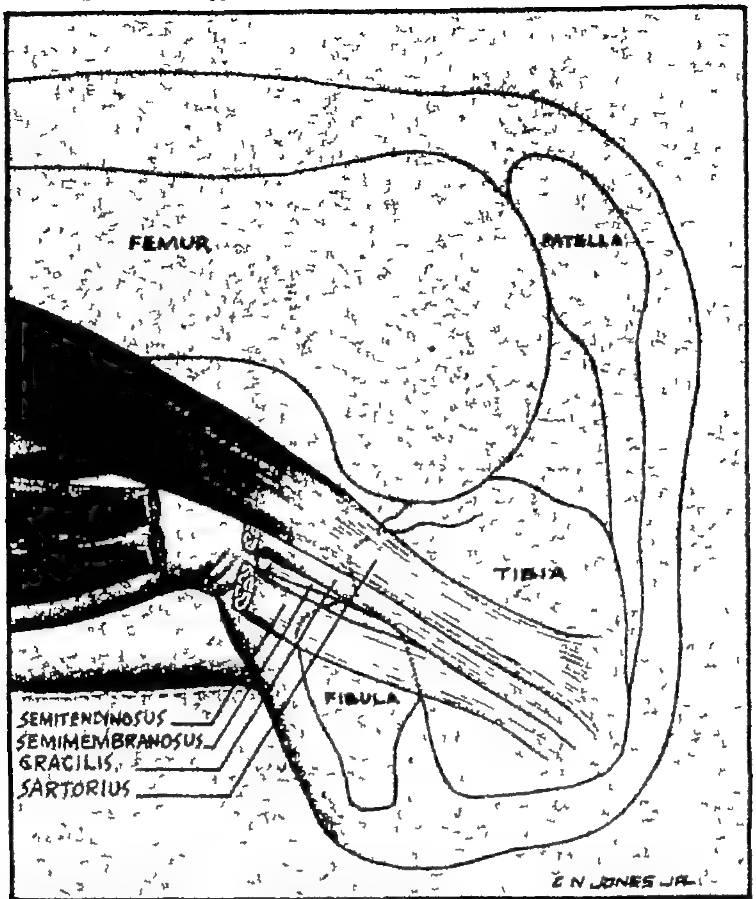
The tibia is beveled and sectioned in the usual manner, but the fibula is *routinely* excised The short below-knee stump does not afford a perfect lever arm, and its fit within the prosthesis is highly important Experience has demonstrated that fit is far more satisfactory, and the incidence of secondary breakdown, painful stump, and bursal formation is decidedly less frequent when the fibula is removed It is usually removed through the open wound during surgery If this step has been neglected, however, excision may be carried out *at a later date through a longitudinal incision placed on the lateral aspect of the leg* This creates an additional scar on the stump, and care should be taken that it will lie at least one and one-half inches below the head of the fibula in order that it will not receive pressure from the weight-bearing area of the prosthesis

Special Techniques in Short Below-Knee Stumps

Following are two special techniques which may be used to advantage under certain circumstances in the short below-knee stump

1 Conservation of the Short Below-Knee Stump by Tendon Section

Blair and Morris have called attention to the increase in functional stump length which may be obtained by section of the hamstring muscles at the level of the knee joint This allows the skin to shift upward into the popliteal space and prevents the hamstring muscles from crowding the prosthesis from the stump as they tense during flexion About two inches of usable stump length



SECTION OF HAMSTRINGS IN SHORT BELOW KNEE STUMP TO FACILITATE PROSTHESIS

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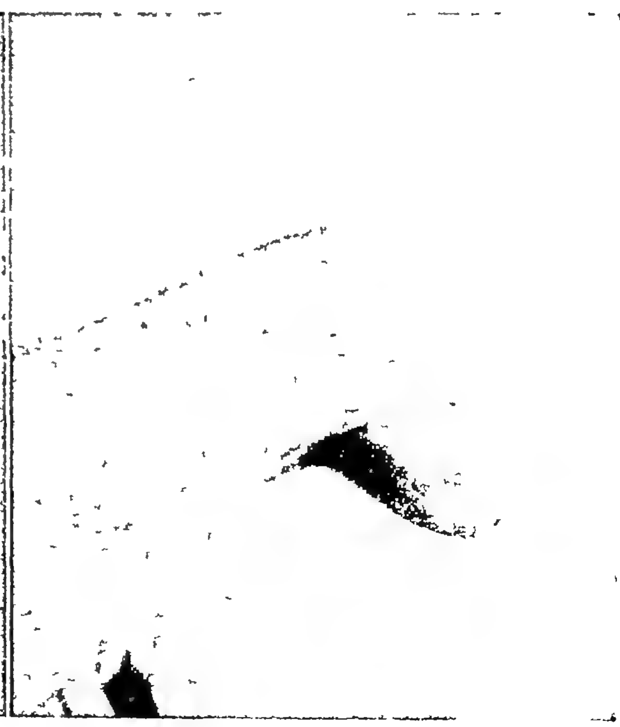

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Figs 240 and 241—Short below-knee stump before and after hamstring section (Courtesy of Blair, H C, and Morris, H D J Bone & Joint Surg 28 427, 1946)

are gained by this procedure When it is performed, there is loss of power in flexion, but this loss is of minor importance and is partially compensated for by the weight of the prosthesis Hyperextension of the knee joint has not been found to occur

Technique

"In the short leg stump, the fibula is excised routinely during the plastic repair, the biceps femoris tendon is severed from its insertion at this time Without any further procedure, it retracts far enough to accomplish the desired purpose The medial limb of the incision used in shaping the flaps is carried sufficiently high to section the semimembranosus and gracilis tendons so that they are allowed to retract If extension of this medial incision will endanger the blood supply in the flap, a small separate transverse incision is made in the fold of the popliteal space, and the same tendons are sectioned through this incision " Blair and Morris have not found it necessary to section the sartorius in any case In a few patients who have had final surgery without section of the hamstrings, the medial hamstrings have been cut at a second operation by the technique described

2 The Bent-Knee Amputation

A bent-knee amputation is one in which a short below-knee stump is flexed to right angles so that the weight may be borne in the kneeling position It is reminiscent of Stevenson's immortal John Silver Before the advent of the modern artificial limb, it was the only practical lower extremity amputation, for the type of stump it created was the only one which could function successfully in the peg leg over a prolonged period It is still considered one of the best end-bearing amputations The patient with the bent-knee stump has tremendous endurance and can perform hard manual labor over long periods of time with little effort and without danger of stump breakdown if the prosthesis is properly fitted It is indicated (1) where irreparable flexion contracture of the knee is present, (2) where, due to contracture or lack of length, a below-knee stump is of no functional value, and reamputation through the thigh is not feasible because of extensive tissue damage, or because the patient s general condition will not stand a major surgical procedure, and also (3) where a peg leg is to be worn either for occupational reasons or because of the lack of availability of standard prostheses It is contraindicated in women for cosmetic reasons, and in office workers because of the bulk of the limb at the knee level

There is no special technique for performing this type of amputation, but there are certain specifications for the stump itself (1) The suture line must be terminal, (2) the weight-bearing surface and the popliteal space must be free from tender scars and any projecting bony prominences, (3) the knee must be flexed to right angles (Hulnick has used quadriceps lengthening in some cases to achieve this), (4) the bone length need be only an inch or two beyond the popliteal space The length requirement has undergone considerable change since the adaptive devices of the artificial limbs have been improved It used to be necessary to have bone length of a full hand's breadth below the back of the flexed knee in order to maintain the prosthesis

A very satisfactory prosthesis, similar in type to that used in end-bearing amputations about the knee, can be constructed for the bent-knee stump Although gait is somewhat awkward with it, as with other limbs which contain no friction mechanism at the knee, it is much more comely than the peg leg The peg leg, however, is dependable and durable, and its cost is minimal It is frequently preferred by loggers and others whose occupations require them to

travel over rough ground with heavy undergrowth in which the artificial foot of the conventional type of limb is constantly becoming entangled It is the choice also in many tropical countries where the conventional limb disintegrates under the attack of fungi, heat, and moisture, or because of excessive sweating

AMPUTATIONS THROUGH THE THIGH

Amputations through the thigh are classified into two groups, the end-bearing, and the ischial-bearing, and these are dependent upon the level at which severance of the extremity is performed Any amputation which is carried out through the distal portion of the thigh, between the knee joint and the supracondylar region, is an end-bearing amputation, that is, both stump and prosthesis are designed in such a fashion that the major portion of the body weight will be carried directly over the extremity of the stump Amputations which are carried out above the junction of the middle and lower thirds of the thigh are ischial-bearing, that is, the stump and the type of artificial limb which is adapted for it are planned so that the greater part of the body weight is carried on the ischial tuberosity Between the supracondylar region and the middle third of the thigh is a small area through which amputation is undesirable, the quality of the skin and the diameter of the shaft of the bone at this level are not conducive to good end-bearing, and the stump which results is too long for ischial-bearing since the extra length serves no useful purpose and is awkward to fit within the prosthesis Both the end-bearing and the ischial-bearing amputations are highly satisfactory as long as the basic rules of amputation are carried out, and the prosthesis is well fitted, but the former is to be preferred, when possible, for it provides a stump which is usually more comfortable over a prolonged period

One of the most frequent and most disabling complications of the thigh stump is flexion contracture of the hip It results in loss of power, decrease in the length of stride, and difficulty in the proper fitting of the prosthesis In mild contractures, the patient is able to wear an artificial limb, but the gait is labored and awkward If the deformity is severe, the stump may be completely functionless and the amputee may not be able to wear a prosthesis at all Although bone and tissue destruction, or disease, sometimes give rise to flexion contracture, poor bed posture is the most common etiological factor It is usually the result of improper postoperative care The malicious habit of propping pillows beneath a recently operated thigh stump gives free play to the hip flexors, which normally overbalance the extensors in the thigh stump Adaptive shortening of the soft tissues follows, and the contracture becomes fixed Occasionally, poor posture in stance and gait occurs because the stump is painful, and the patient finds that flexion affords relief If he habitually favors the stump in this manner, deformity will ensue The painful stump is most commonly caused by the cicatricial shortening of an incision overlying the anterior aspect of the hip joint Proper bed posture should be assured throughout postoperative care to prevent deformity from that source The hip should be in the neutral position with no pillows beneath the stump If necessary, a plaster of Paris hip spica should be employed to ensure that proper posture is maintained Exercise and mechanical stretching, as described in the section on physiotherapy, are preventive measures which should also be taken routinely These and the use of the artificial limb will relieve mild flexion contracture which is being caused by painful stump, or which has already become fixed through poor posture In the more severe deformities, where structural changes have taken place within the soft tissues, or there is bone involvement or disease surgery must usually be

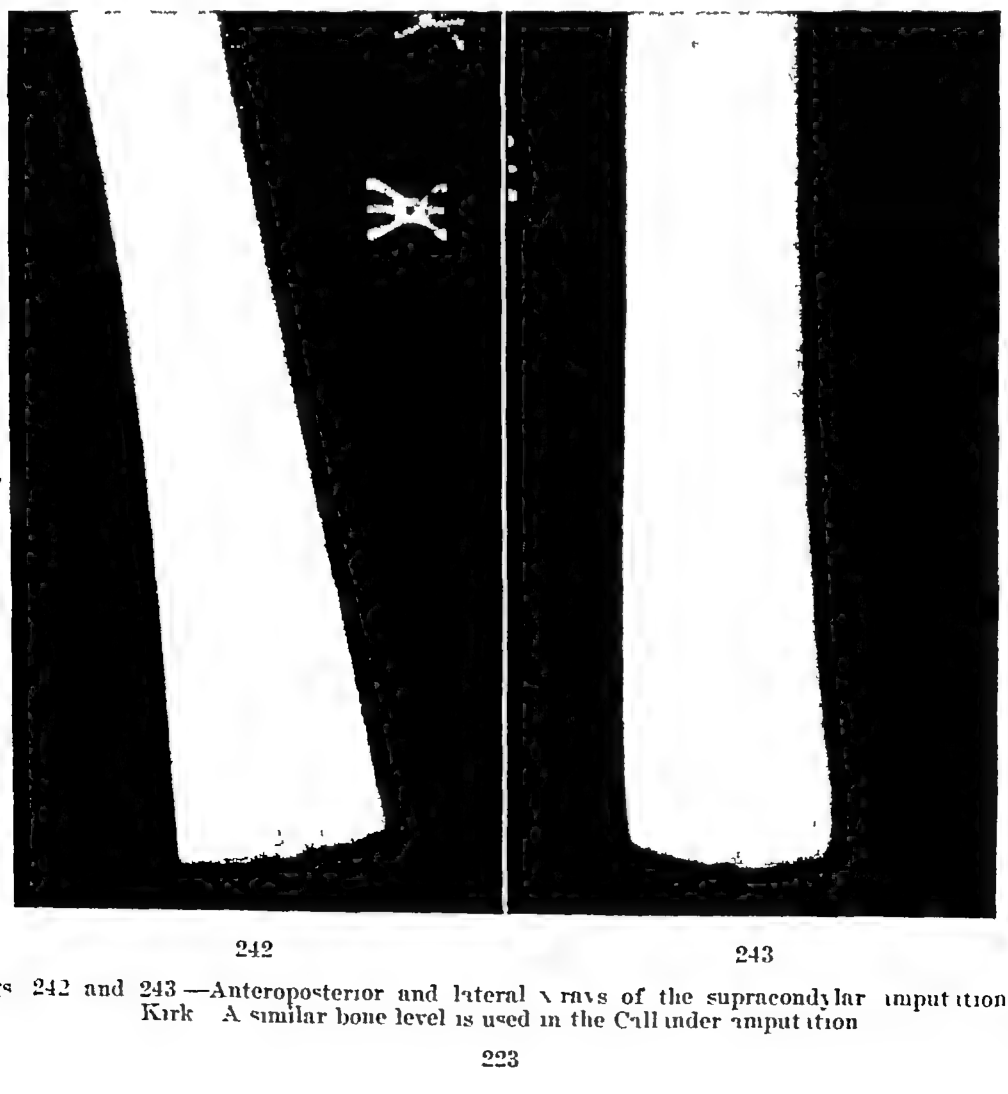
resorted to Massive wounds often result in soft tissue change for they become healed by scar, and the large defect created by the extensive loss of tissue becomes one great block of fibrotic cicatrix When such a mass lies upon the anterior aspect of the thigh or hip, flexion contracture usually occurs, for the shortening of the scar gradually draws the thigh forward and fixes it against extension Such a situation demands plastic revision of the soft tissues with block resection of the cicatrix In cases where the distortion of the soft tissues in this area is extremely severe, and in those cases where flexion contracture is due to bone involvement, such as fracture deformity of the upper end of the femur, or an unrecognized posterior dislocation of the hip, osteotomy should be performed in accordance with the usual orthopaedic principles A word of caution should be interjected here Incisions should be so placed that they do not lie over the bony prominence of the greater trochanter, for the artificial limb will rub against the scar Joint disease which has led to destruction of the articular surface may also result in flexion contracture In such an instance, reconstruction of the joint is indicated When there is paralytic loss of function of the extensor muscles, the dominant flexor muscles draw the hip into flexion deformity Contracture in such a case is the result of interruption of the nerve pathways or loss of muscle substance, and there is no procedure, surgical or otherwise, which can reverse it

The End-Bearing Amputations

The aim of the end-bearing amputation is a purely functional stump In order to be functional it must be long enough to provide a strong lever arm with which to control the limb, and the bone end and its covering must be such that they can carry direct weight without breakdown Since these amputations are only performed through that part of the thigh which is at or distal to the supracondylar level, sufficient bone length is assured and, in addition, the power for motivation of the artificial limb is excellent, due to the fact that the muscle insertions are retained at their normal length and eventually become fixed to bone Its weight-bearing capabilities are another matter They are dependent largely upon the judgment and skill of the amputation surgeon, for he must create a stump end which, as nearly as possible, simulates natural weight-bearing surfaces, and which will fit within the prosthesis comfortably Rogers has pointed out that the only tissues which are normally subjected to pressure are (1) finely trabeculated cancellous bone surrounded by a thin cortex, and covered by hyaline cartilage or adherent periosteum, (2) the tendinous origins and insertions of muscles, (3) secretory pouches such as joints and bursae, and (4) areolar tissue and skin of a congenitally specialized variety A functional end-bearing stump will almost uniformly be achieved, if the structures are considered in this light, and if the following basic requirements are rigidly adhered to First, the extremity must be absolutely free from infection before surgery is undertaken This applies to both local and regional infection The probability of wound breakdown following reactivation of local infection is always taken into account However, it should be remembered also that active sepsis, even though lying far distal to the site of operation, often disseminates, through lymphatic channels, an abundance of pathogenic organisms which will frequently become active when provided the pabulum of the amputation wound Second, there must be sufficient padding over the bone end Its cut surface may be protected by the quadriceps tendon, the patella, or the enucleated patellar bed together with the adjacent extensor fascia Third, the skin covering the end of the stump must be of normal quality It must be free from scar and

have normal sensation and vascularity Scars overlying the end of the stump are subject to breakdown with the use of the prosthesis, trophic changes will follow when the skin lacks sensation, inadequate tissue nutrition causes the stump to become dull red and cyanotic and palpably cool—such a stump will break down under minimal trauma Circulatory embarrassment may follow in the wake of an old injury which has left extensive intra- and subcutaneous cicatrix, or it may arise after surgery from drawing the skin too tightly over the stump end or from the constant irritation of a malfitting prosthesis Fourth, the supporting bony base must be smooth, rounded, and so oriented that the flat surface is parallel to the ground in order that weight will be received evenly upon it and not be concentrated at one point It should be of adequate size to carry the superimposed weight Note should be made here of the factors which influence the size of the weight-bearing surface If satisfactory in other respects, the greater the size of the bearing area, the greater the distribution of load, and the greater the tolerance of the skin It is for this reason that an attempt to create an end-bearing stump above the supracondylar region does not meet with success, for the cortical bone of the diaphysis presents too small an area, and the pressure concentrated upon its skin covering is greater than that tissue can tolerate On the other hand, the greater the size of the bearing area, the more difficult is the adjustment of the artificial member (And yet—contradictory as it may seem at first glance—the very bulk of the stump makes it possible for the prosthesis to be fitted without excessive harness) Thus it is that disarticula-

BONE LENGTH AND FORM IN END-BEARING AMPUTATIONS OF THE THIGH



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Figs 242 and 243—Anteroposterior and lateral x rays of the supracondylar amputation of Kirk A similar bone level is used in the Callander amputation

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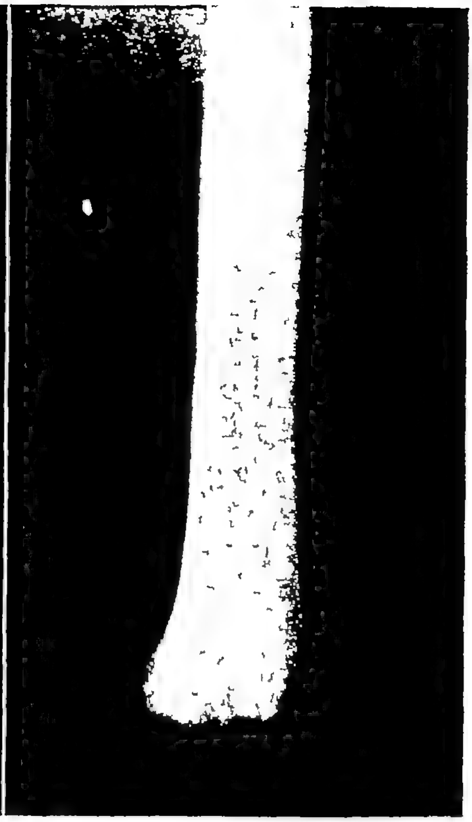

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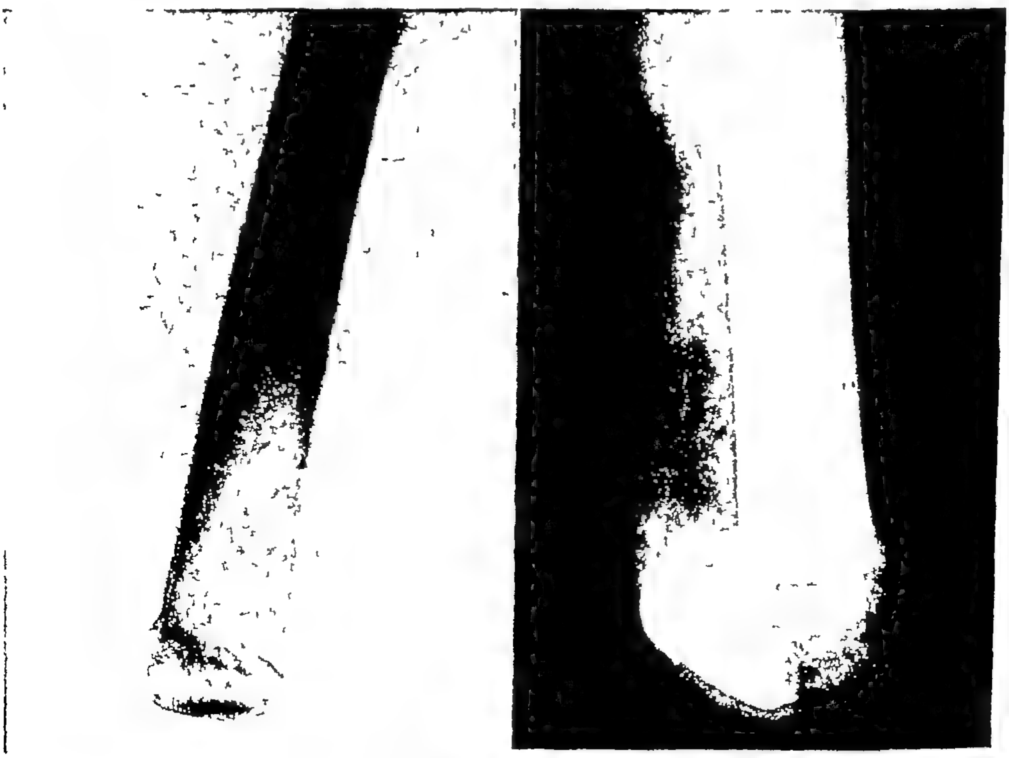
Figs 244 and 245—Anteroposterior and lateral x-rays of the rounded epicondylar amputation



A

B

Fig 246—Gritti Stokes amputation A, Anteroposterior x ray showing bone level and arthrodesis B Lateral x ray of poorly performed Gritti Stokes amputation with loss of fixation and forward dislocation of the patella

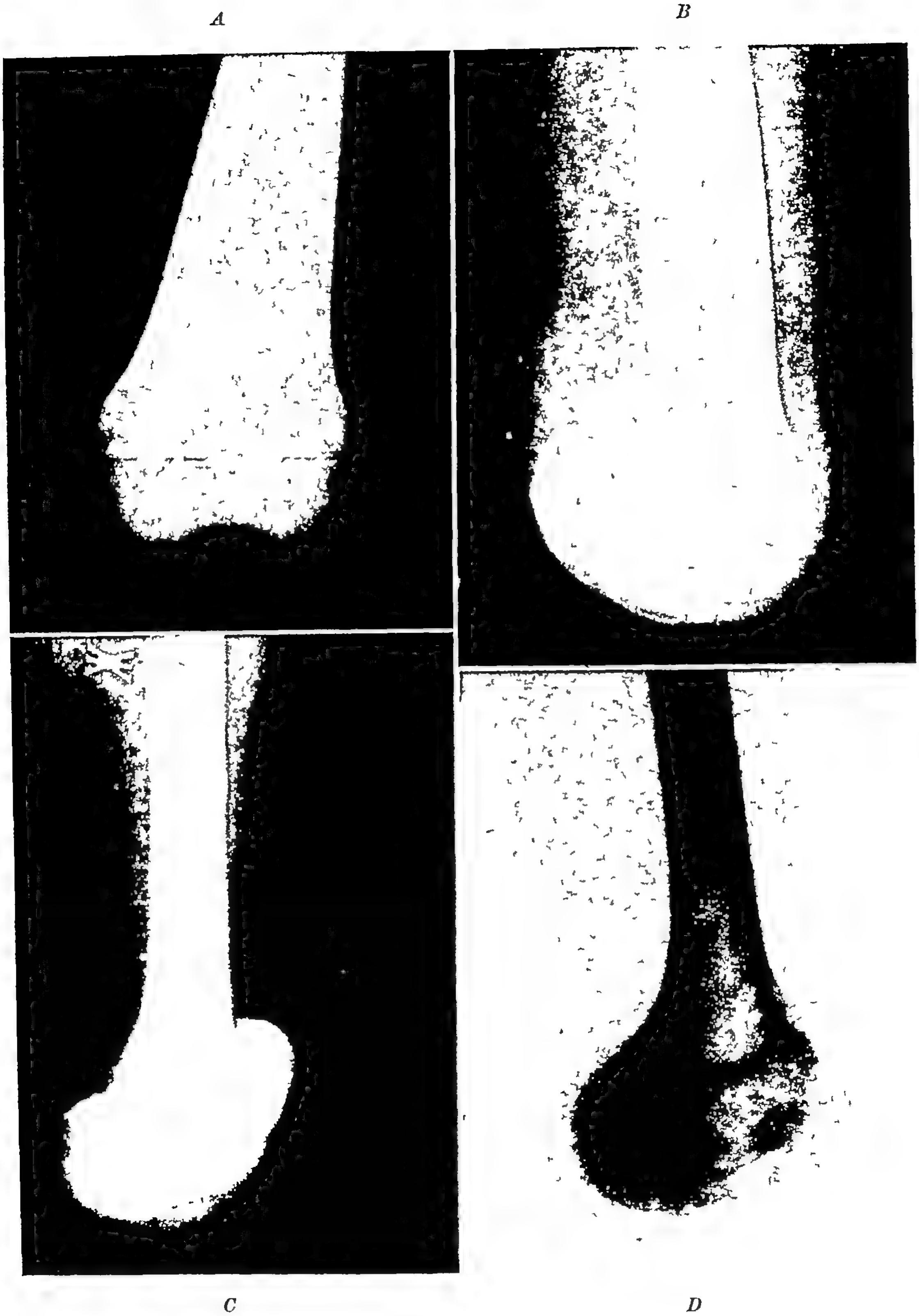


Fig 247—Disarticulation of the knee

A, Anteroposterior x-ray

B, Lateral x ray with patella removed (England General Hospital Neg No RC328)

C, Lateral x-ray with patella remaining (England General Hospital Neg No RC336)

D, Lateral x ray with patella fused to the femur after the technique of Rogers (Courtesy of Rogers, S P J Bone & Joint Surg 22 973, 1940)

tion of the knee, which presents the broadest surface, is the most difficult to fit because of the bulbous femoral condyles, while the supracondylar and epicondylar amputations may be fitted with relative ease. It is evident that a compromise must be made between the size of the weight-bearing surface and the fit of the prosthesis.

The end-bearing amputations may be classified in three categories: (1) tendoplastic amputations, (2) osteoplastic amputations, and (3) disarticulation. In the first group are those in which the bone end is covered by the quadriceps tendon and its fascial and tendinous expansions. In the second are those in which pressure is transmitted directly from the skin to a bone which has been arthrodesed to the femoral shaft. It includes the Stokes-Gritti and the obsolete Sabanjeff amputation. The latter employs the anterior surface of the tibial tubercle over the end of the bone and has been discarded in favor of the short below-knee, or technically simpler end-bearing amputations. The third, disarticulation, employs the use of weight-bearing on the fascial extensor expansion and articular surface of the joint. It has been found to be very satisfactory in the hands of a few surgeons.

The Tendoplastic Amputations

The Aperiosteal Supracondylar Tendoplastic Amputation of Kirk

This amputation is carried out through the lower third of the femur at a bone level one and one-fourth inches above the articular surface on the anterior aspect of the femur. This represents the point at which the quadriceps tendon may be brought over the bone end and sutured to the posterior fascia without tension. A long anterior flap is formed, containing the quadriceps tendon which is used to cover the bone. This is an excellent level of amputation and gives a less bulky stump than the other types which are carried out more distally. A tourniquet is used except when the amputation is performed in the presence of peripheral vascular disease. The skin flaps are so planned that there is a long anterior flap and a short posterior flap in the relationship of 4:1.

Technique

1. *The skin incision* begins at a point midway between the anterior and posterior surfaces of the thigh immediately above the bone level. It passes distally and anteriorly to cross the anterior aspect of the thigh just below the upper margin of the patella. It then swings proximally to the mid-lateral aspect of the thigh opposite the starting point of the incision. The posterior flap is formed by connecting the two upper extremities of the anterior flap by an incision in the back of the leg with a slight downward convexity.

2. *Formation of the flaps.* Both incisions are deepened to the level of the fascia and the skin is allowed to retract. The anterior incision is deepened to bone just above the level of the retracted skin, and the quadriceps tendon is severed at its patellar insertion. The anterior flap now consists of skin and musculotendinous tissue formed by the extensor mechanism of the quadriceps muscle. (These two layers should not be separated.) It is now reflected upward, exposing the suprapatellar bursa, which is carefully dissected out so that later bursal irritations will not lead to accumulation of synovial fluid. The posterior flap is formed by cutting the posterior fascia at a point one-fourth inch below the level of the retracted skin. The muscles and the other soft parts are sectioned in such a manner that they will fall at the level of the saw line, and the flap is reflected upward.

3. *Section of the bone.* A circular periosteal incision is made at the intended bone level, the bone is sectioned, and a one-fourth inch periosteal cuff is removed

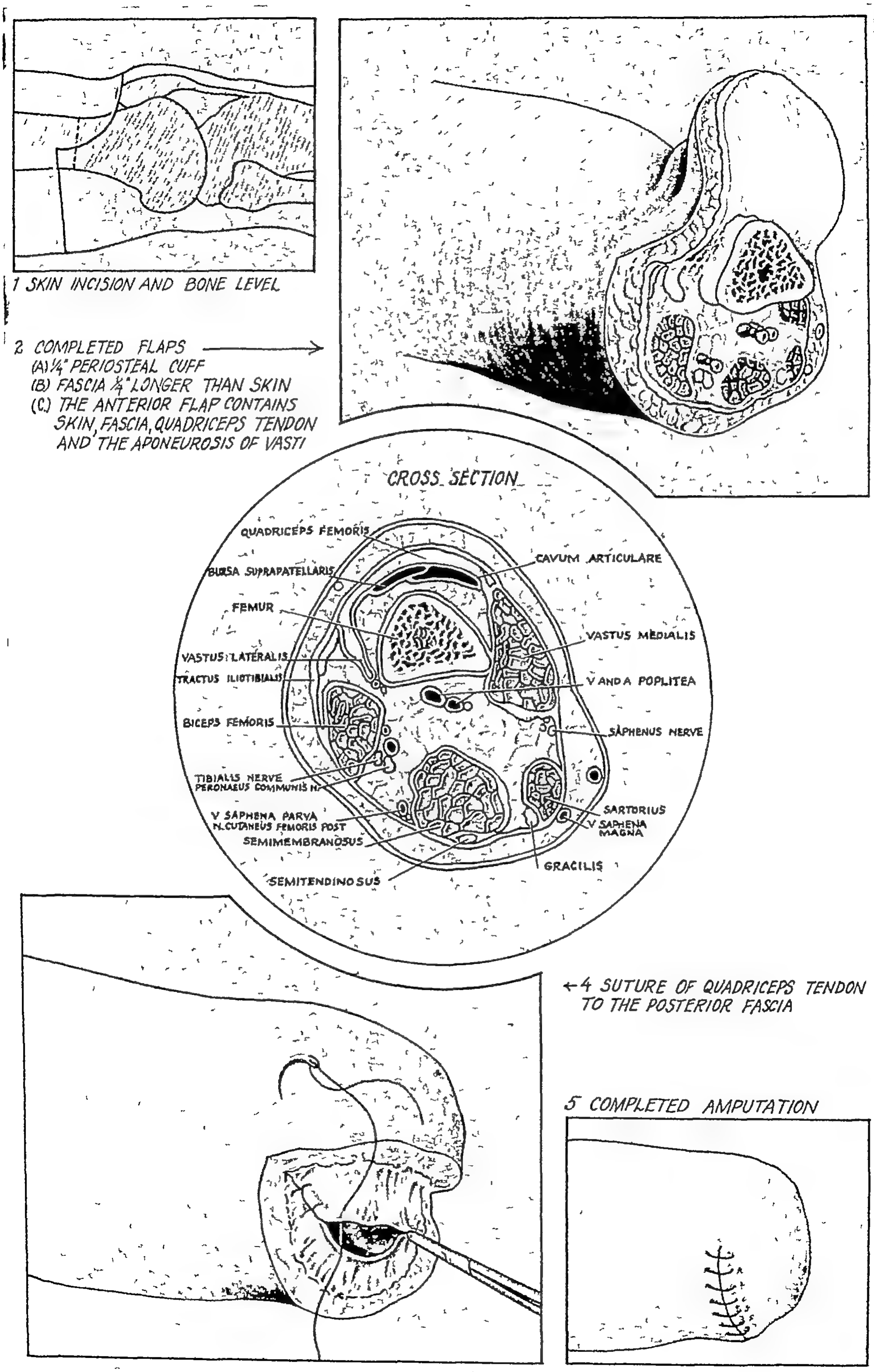


Fig 248 —The aperiosteal supracondylar tendoplastic amputation of Kirk

The cut surface of the bone should be on such a plane that it would be parallel to the floor if the patient were in the standing position. Section at right angles to the long axis of the femur will not achieve this angle because of the normal valgus of that bone, and if such is performed, a prominent lateral margin will be present which may be painful on weight-bearing.

4. *Care of vessels and nerves.* The femoral vessels are isolated and doubly ligated with catgut. The sciatic nerve, or its two branches, the tibial and common peroneal, are isolated, pulled down gently, and ligated. Ligation of this nerve is advisable at this level since a small artery is often present within it which may lead to troublesome postoperative bleeding. Other nerves are sectioned and allowed to retract. If a tourniquet has been used, it is now released and hemostasis is secured.

5. *Closure.* The anterior flap of muscle, tendon, and skin is now fixed to the posterior flap by interrupted suture. Care is taken that the quadriceps tendon falls directly over the bone end. The skin is closed with interrupted sutures, and drains are placed in both ends of the wound in such a manner that they lie beneath the musculotendinous flap.

6. *Postoperative care.* The wound is covered with a dry gauze dressing and snugly fixed with several elastic bandages extending to the level of the groin. The drains are removed in forty-eight to seventy-two hours, and the dressing is reapplied. Sutures are removed on the fourteenth day. Bandaging is continued until the stump has reached its normal shrinkage. Stump toughening exercises, including tapping and weight-bearing on soft surfaces, are instituted at the end of the third week.

The Rounded Epicondylar Tendoplastic Amputation (Author's Method)

This amputation represents a compromise in which a broad weight-bearing surface is provided and the stump may still be easily fitted with a satisfactory artificial limb. Pressure is received on the broad "U-shaped" anterior flap of skin and extensor tendon overlying the rounded bony expansion of the epicondylar flare. In theory, it is a combination of the bone level and contour suggested by Carden in 1864 and the more recent tendoplastic methods of Kirk and Callander. On the basis of my observation of thirty-eight cases successfully treated in this manner, I feel that this method is superior to other types. The final stump is comparable to that obtained by the Stokes-Gritti procedure but has the advantage that there is no risk of failure of fusion between the patella and the femur.

TECHNIQUE

1. *The skin incision.* The incision starts at the adductor tubercle of the medial epicondyle and passes distally and laterally to cross the front of the knee at the level of the insertion of the patellar tendon to the tibial tubercle. Thence, it swings proximally along the lateral side of the knee to end at the upper border of the lateral epicondyle of the femur. The posterior incision traces an arc which joins the two ends of the first incision, forming a flap three-quarters of an inch in length.

2. *The development of the anterior flap.* The anterior incision is deepened through the tendon and fascia of the front of the knee to expose the joint. The flap is reflected upward, and the patella is excised from it by sharp dissection. The synovial membrane and any excessive fat about the bed of the enucleated patella or around the anterior fat pads are trimmed away.

3. *Bone section.* The bone is sectioned parallel to the ground at the level of the femoral epicondyles. The cross section of the bone is broad and irregular

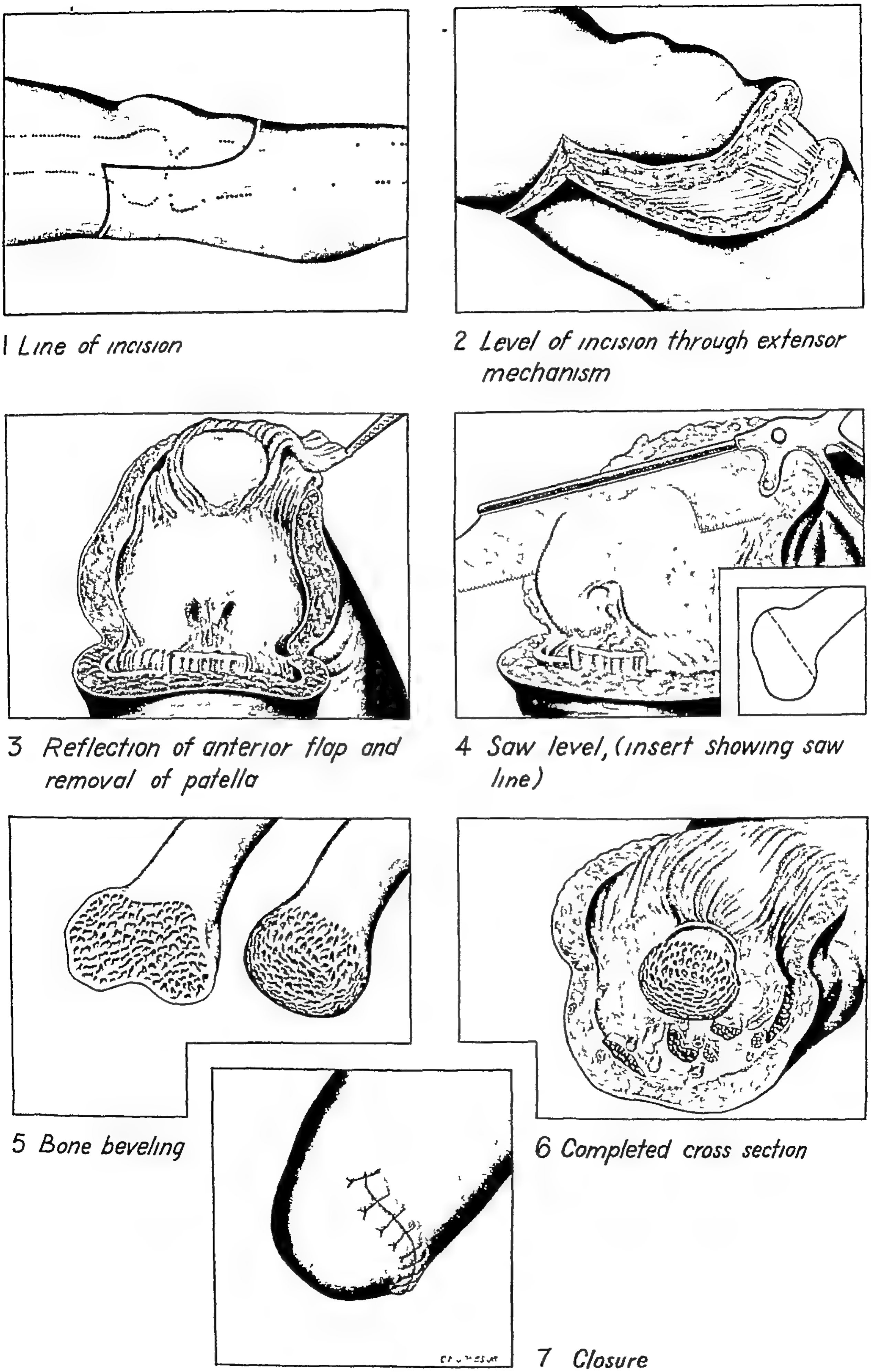


Fig 249.—The rounded epicondylar tendoplastic amputation

at this point and must be rounded if it is to be satisfactory This is accomplished by beveling the edges of the cut bone at an angle of 45 degrees, starting at a point one-half inch within the periphery Either a saw or a rongeur may be used All sharp edges are smoothed with bone file or rasp until the bone end is roughly hemispherical in shape except for its broad, flattened end All bone dust is washed away

4 *Section of the posterior soft tissues* The severed femoral condyles are retracted downward to expose the posterior soft tissues of the thigh The neurovascular bundle, flanked by the hamstring muscles, is now clearly visible The popliteal artery and vein are sectioned between two clamps and doubly ligated with plain No 2 catgut The sciatic nerve (or its two components, the posterior tibial and common peroneal nerves) is drawn down gently and sectioned so as to fall well above the bone end A fine catgut ligature is usually placed about the cut nerve end to control bleeding from the small vessel which lies within it The hamstring tendons are easily freed by finger dissection and are sectioned at the bone level and allowed to retract The posterior fascia of the thigh is now exposed It is sectioned at a point three-quarters of an inch distal to the retracted skin of the posterior flap The tourniquet is removed and hemostasis is secured

5 *Closure* As the anterior flap of skin, tendon, and fascia is swung posteriorly into place, the bed of the patella is fitted over the bone end The tendinous portion of the anterior flap is then approximated to the posterior fascia by interrupted sutures The skin is closed with interrupted sutures, preferably of No 34 stainless steel wire A drain is placed between the first and second sutures, where the tension is sufficient to close the aperture when the drain is removed Dry dressings are applied, followed by a compression dressing of sheet wadding and elastic bandage extending from the groin to the end of the stump

Postoperative Care

The drain is removed at the end of forty-eight to seventy-two hours, depending upon the amount of drainage Dry dressings and elastic bandage are continued until the fourteenth day, at which time the stitches are removed Elastic bandaging is continued until shrinkage of the stump is complete It should be re-emphasized that the *bone end must be carefully rounded* If this is not done, the result will be difficult closure and an unsatisfactory stump These have been the classical objections to the transcondylar and epicondylar amputations

The Callander Amputation

The Callander amputation is a method of amputation primarily designed to be used in the presence of vascular disease, and under these conditions it is the procedure of choice It has as its principles the creation of long anterior and posterior flaps, the affording of free drainage from the end of the stump, the section of all muscles through their tendinous insertions, and the elimination of all coapting deep sutures One of its most outstanding features is the manner in which the flaps are formed and arranged over the end of the stump They are of equal length and are cut extra long, they are not tailored but are left loose, being approximated roughly with four to six widely separated sutures This allows free drainage and eliminates any possibility of tension The posterior tissues in this area naturally retract more extensively than the anterior, and, as healing takes place, the suture line is drawn proximally on the posterior surface, so that it lies well away from the pressure area This retraction also automatically collapses any dead space always a source of potential infection Possibility of sepsis is further minimized by another special feature of this procedure muscles are severed through their tendinous insertions, so that the continuity of

the muscles themselves is not interrupted, and their planes cannot be invaded by ascending, virulent, pyogenic organisms Since this amputation is carried out through an avascular plane, no tourniquet is necessary, and thus further damage to the blood vessels is avoided There are no redundant masses upon the stump, so that it fits well within the prosthesis with minimal trauma from friction and pressure

Position The patient is placed in the dorsodecubitus position with the knee flexed to 150 degrees It is maintained at this angle by sandbags placed beneath it The surgeon stands on the side opposite from the thigh to be operated upon, facing its medial aspect

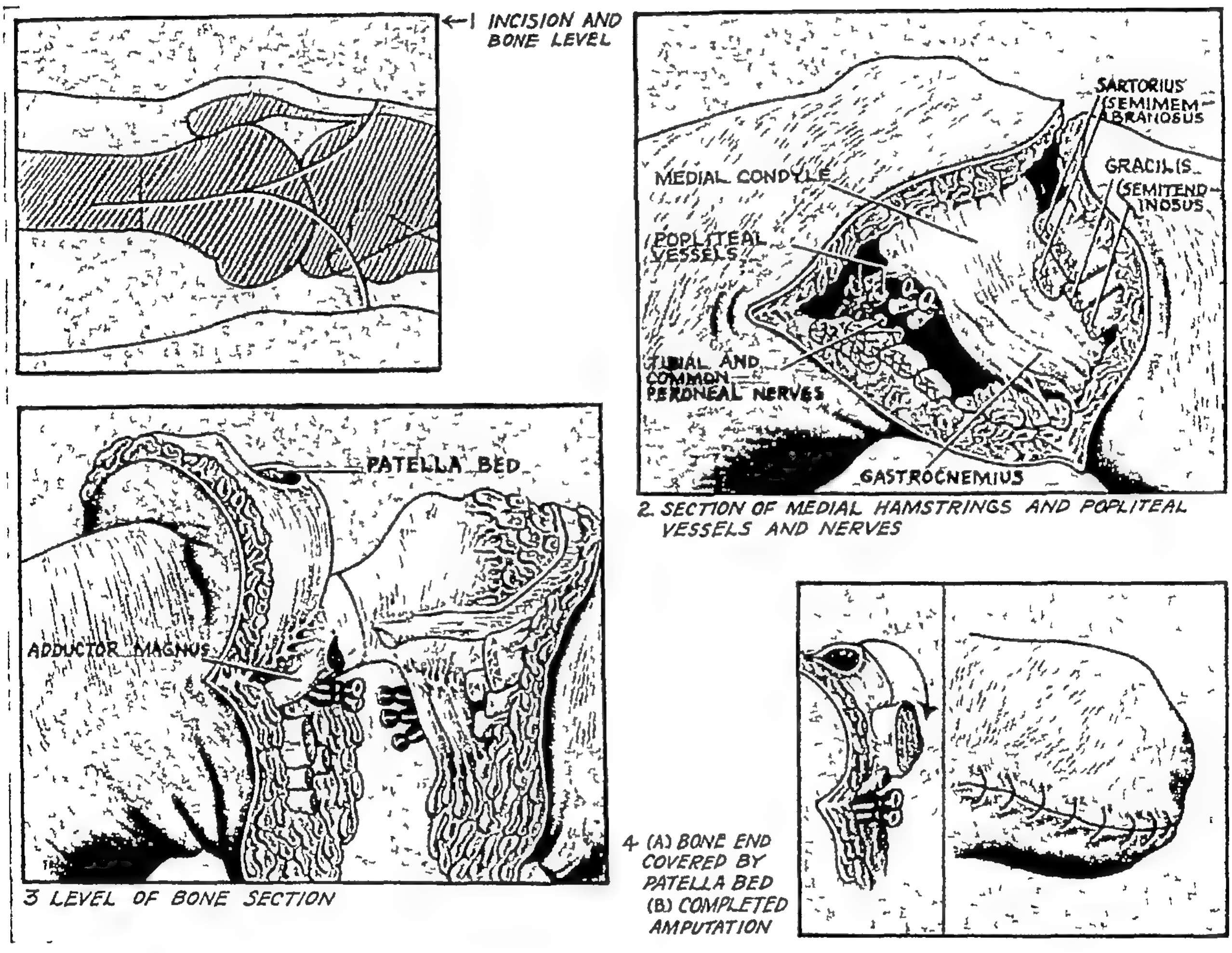


Fig 250—The Callander amputation

Technique

1 *Skin incision* The incision starts on the medial aspect of the thigh at a point three fingerbreadths above the most prominent part of the medial femoral condyle It then passes distally in the groove between the vastus medialis and the sartorius muscles which is easily defined when the knee is in flexion The incision continues in a distal-lateral curve to a point over the tibia just below the insertion of the patellar tendon to the tibial tuberosity The thigh is now rotated medially Another incision begins on the outside of the leg at a point three fingerbreadths above the lateral femoral condyle and follows just anterior to the groove between the tendinous fascia lata and the biceps femoris tendon (When it is deepened, the fibers of the tendinous fascia lata must be split in order that the muscle fibers of the biceps may be avoided) The incision then swings in a distal-medial curve over the lateral epicondyle to join the medial

incision overlying the tibial tubercle. A posterior flap of equal length is created by incisions made in the same manner on the posterior aspect. Their most proximal points are at the femoral epicondyle and their most distal at the midline of the calf behind the tibial tubercle. All incisions are deepened to the fascia.

2. *Section of the posterior-medial soft tissues.* The thigh is externally rotated and the medial fascia is sectioned. The medial hamstrings are then freed by finger dissection. These tendons are sectioned from anterior to posterior in the following order: sartorius, gracilis, semimembranosus, and semitendinosus. They are then allowed to retract. The adductor magnus is next identified at its attachment to the adductor tubercle on the medial condyle of the femur and severed through that insertion. The dissecting finger is now placed in the popliteal space to identify the popliteal artery and vein, which are doubly clamped, ligated, and divided at the most distal point possible in the popliteal space. The tibial and common peroneal nerves are identified and sectioned.

3. *Section of posterior-lateral soft tissues.* The knee is internally rotated. The deep fascia, including the fibers of the tensor fasciae latae, is divided, and the biceps femoris tendon is sectioned at its insertion. The incision is then deepened as far down as the gastrocnemius aponeurosis.

4. *Section of the anterior soft tissues.* The knee is placed in extension and the incision is carried down through the capsule of the knee joint and the patellar tendon by following the outline of the anterior skin flap. The flap is reflected upward, and the patella is enucleated by sharp dissection close to the bone. No attempt is made to excise the synovial membrane.

5. *Bone section and closure.* The femur is sectioned transversely just proximal to the adductor tubercle at a point where the transverse diameter of the femur corresponds with the cavity left by the enucleated patella. The bone is smoothed, the entire wound is washed with large quantities of saline, and absolute hemostasis is secured. The anterior and posterior flaps are now allowed to fall loosely together and are approximated by four to six interrupted sutures. These flaps are very loose and may often extend an inch or more beyond the bone end. Retraction takes place very rapidly due to the hamstring contraction and the elasticity of the popliteal skin.

Postoperative Care

The stump is wrapped with a gauze roll and a posterior splint is applied. Daily dressings are carried out because of the serous accumulations. The posterior flap very rapidly retracts, and soon the suture line lies well behind the distal end of the femur. Sutures are removed between the tenth and fourteenth days.

The Osteoplastic Amputations

The Gritti-Stokes Amputation

This is an excellent end-bearing amputation and is used as the procedure of choice by the Canadians, who have employed it more extensively than any other group.

Operative Plan. In principle, it consists of a short posterior flap and a long anterior flap which contains the patella. The latter is rotated 90 degrees and is then arthrodesed to the femur in the supracondylar region where it forms the bony weight-bearing area.

Technique (LeMesurier)

1. *The incision.* The anterior incision begins at a point one inch above the superior border of the patella in the mid-lateral position, swings distalward and curves across the anterior border of the knee at a point one-half inch below the

lower pole of the patella It then passes proximally along the medial side of the leg to a site opposite the starting point of the incision The posterior flap is formed by an incision which connects the two ends of the anterior incision It reaches a maximum length of one-half inch in the mid-point of the popliteal space

2 *Section of the soft tissues* The anterior flap is deepened into the joint by dividing the anterior capsule of the joint and the patellar tendon The anterior flap is reflected upward, revealing the suprapatellar bursa The posterior flap is retracted upward, and the muscles are divided by a slightly oblique section starting near the skin and extending distally to reach the femur just above the condyle The vessels and nerves are treated as if a tendoplastic supracondylar amputation were being done

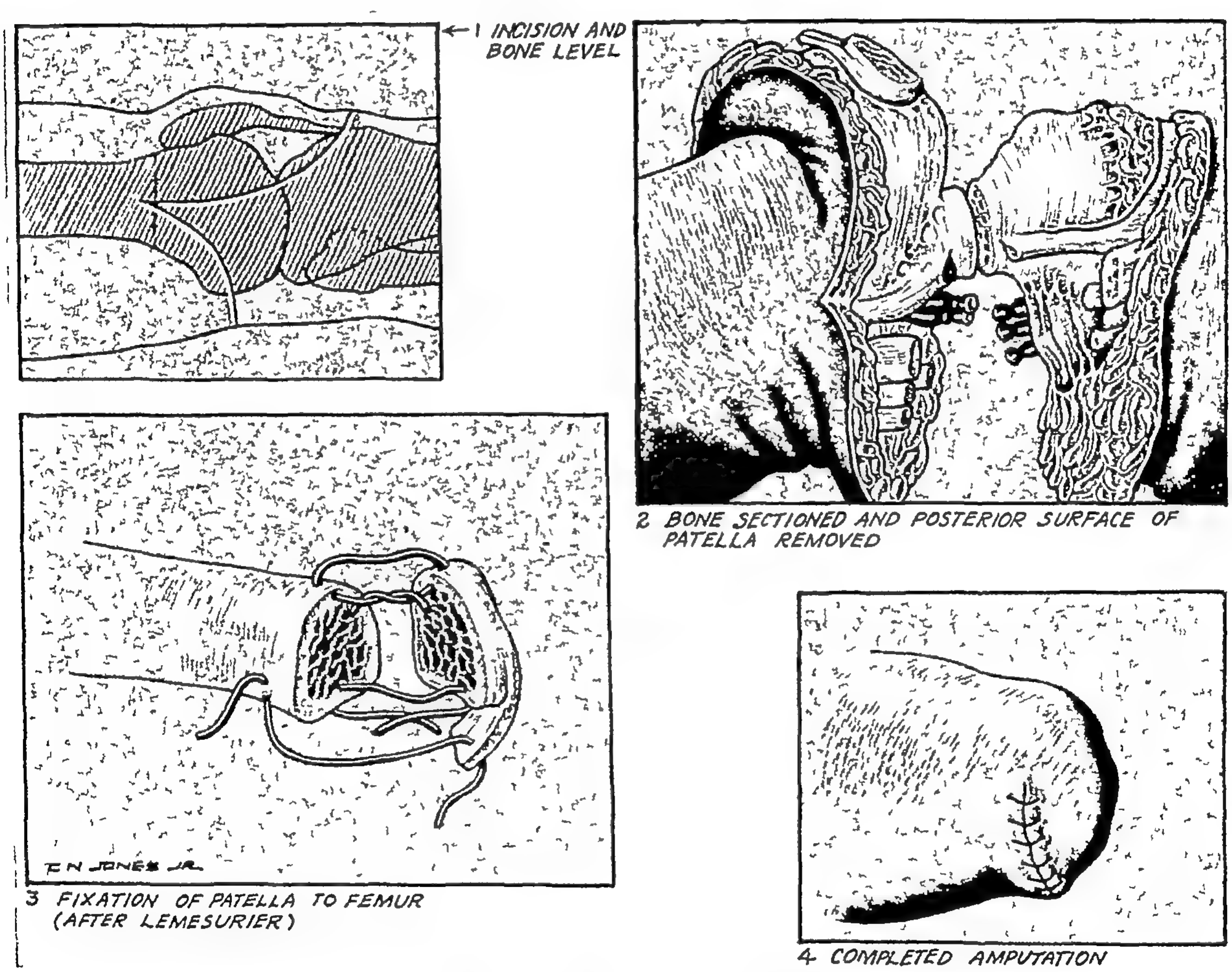


Fig 251 —Gritti Stokes amputation

3 *Treatment of the bone* The proper bone level lies distally in the supracondylar area and is at the point where the femoral cross section is about the same size as the diameter of the patella This allows the patella to rest solidly in its new position on the cut end of the bone, and the pull of the quadriceps muscle will not upset it The bone is sectioned parallel to the ground if the patient is assumed to be in the standing position The suprapatellar pouch is not dissected away, but any excess tissue is trimmed The border of the patella is freed of synovial tissues, and its posterior one-half including the articular cartilage and a section of bone, is removed A test fit of the patella and distal end of the femur is made, and, when this is satisfactory the anterior flap is

brought posteriorly in order to approximate the cut surfaces of these two bones This position is maintained by two stout catgut sutures which pass through drill holes in both bones, one anteriorly and one posteriorly In placing these drill holes, care should be taken not to put the sutures in such a position that the weight-bearing surface will be disturbed The patellar tendon is now sutured to the periosteum on the posterior aspect of the femur

4 *Closure* The skin flaps are approximated by interrupted suture A drain is placed on either side of the operative wound Dry dressings are used, and elastic bandage compression is applied from the groin to the end of the stump

POSTOPERATIVE CARE

The drains are removed in forty-eight to seventy-two hours Dry dressings and elastic bandages are continued until the fourteenth day, at which time the sutures are removed The stump is kept snugly bandaged, and the patient is not allowed weight-bearing until bony union occurs between the patella and the distal end of the femur

The Sabanajeff Amputation

This procedure is chiefly of historic interest It is based on the principle of arthrodesis of a section of bone from under the tibial tubercle to the cut end of the femur, which has been sectioned transversely at the level of the condyles A short posterior flap and a long anterior flap extending three fingerbreadths below the tibial tubercle are utilized The underlying bone, which is included in this flap, is rotated posteriorly 90 degrees, where it is secured in position for arthrodesis

DISARTICULATION OF THE KNEE JOINT

Although disarticulation had been performed for more than a hundred years, it was not until Perry Rogers brought forward his series of twenty-three highly successful cases that it received popular acclaim Due to a fortuitous combination of adequate surgery and ideal limb fitting, those cases presented excellent results In the hands of the experienced surgeon, disarticulation unquestionably affords an excellent end-bearing surface, but the stump is exceedingly difficult to fit True, its bulbous end has one point in its favor from a prosthetic viewpoint—an artificial member may often be worn without the use of a pelvic belt This advantage, however, is far outweighed by the more serious problem which it creates The projecting femoral condyles, particularly the lateral one, are subject to constant pressure and irritation from the artificial limb, and breakdown may be almost routinely predicted in a poorly fitted prosthesis This procedure should never be attempted unless a skilled limb maker is available

In the presentation of his series Perry Rogers pointed out that disarticulation is a simple and easy procedure since no bone is severed, shock is minimal, medullary bone infection and the danger of fat embolism are avoided, and the tracking of infection through muscle planes is eliminated because no muscle sheath is opened He stated that the requirements for function are fulfilled in the following ways (1) It provides the largest horizontal end-bearing surface area available in the lower extremity (2) The bone, soft tissues, and skin at the end of the stump were all previously adapted to weight-bearing (3) The terminal integuments which receive pressure are not subjected to tension (4) Muscular control of the stump is achieved by preserving the length and attachment of every muscle motivating the thigh (5) Excellent leverage can be exerted on a prosthesis because the stump is long and because its terminal cir-

cumference is both firm and insensitive (6) The triangular tip, composed of patella and two condyles, assures control of rotation of the prosthesis (7) The bulbous shape of the tip allows the stump to lift a prosthesis as the foot lifts a shoe (8) Atrophy is minimized by preserving the function of most of the muscles left in the stump, and by the early use of a permanent prosthesis (9) Vascularity of the terminal tissues is unexcelled Ligation of the popliteal artery below its superior geniculate branches leaves the richest system of arterial anastomoses available in the extremity The greater part of the terminal flap comes from in front of the joint space and therefore already has a blood supply independent of its underlying tissues (10) Preservation of the lower femoral epiphysis, accountable for 90 per cent of the growth of the femur, allows normal development of the stump following amputation in childhood

The operation is here described as it is performed in Rogers' technique

Position The patient is placed in a supine position with the knee flexed, and the surgeon is on the side opposite the extremity to be operated upon

Operative Plan No tourniquet is used A broad anterior flap extending one inch below the tibial tubercle, and a broad posterior flap extending one inch below the flexion crease are created The size of the flaps may vary depending upon the obesity of the patient and the availability of healthy tissues The end result should be a snug covering of the condyles by skin which is maintained by fixation of the underlying myotendinous structures to bone

Technique

1 *Resection of the leg* The deep dissection is carried out first on the inner side The tendons of the four medial hamstrings are exposed and cut as low as possible The popliteal artery is identified and ligated immediately below its superior geniculate branches The tibial nerve is identified, drawn down gently, and allowed to retract The common peroneal nerve may be sectioned either at this time or after the lateral hamstrings are cut The incision is then carried through the deep fascia along the border of the anterior skin flap The patellar tendon is sectioned as close to the tibial tubercle as possible At this point, the skin, fascia, patellar tendon, and synovial membrane are reflected in one undisturbed full-thickness flap The tendon of the biceps and the iliotibial band are exposed and sectioned through their insertions The short posterior flap is reflected upward, and the collateral and cruciate ligaments of the knee are cut close to their femoral attachments The leg may now be separated from the thigh by stripping the heads of the gastrocnemius muscle from the femur

2 *Treatment of soft tissues and bone within the stump* The muscles of the thigh are now attached under normal tension to the end of the stump The patella is fixed to the anterior aspect of the femur either by mortising the patella into a femoral groove, or by denuding the apposing cartilaginous surfaces and affixing the patella to the femur with a screw The patellar tendon is then drawn posteriorly within the intracondylar groove and fixed to the ends of the hamstring tendons The sartorius and the iliotibial band are sutured to the fascial portion of the extensor mechanism No attempt is made to excise the synovial membrane or remove the articular cartilage

3 *Closure* The skin flaps are trimmed for ideal approximation Fascial layers are closed by interrupted catgut and the skin with interrupted silk Dry dressings are applied

Postoperative Care Rogers states that pressure exercises can be started within two weeks after operation, and the stump may be fitted with an artificial limb at the end of six weeks

Alldredge was the chief advocate of disarticulation of the knee in the army amputation centers. He stresses the fact that the anterior flap should be made as long as possible and should be squarish rather than tongue-shaped in order to cover the wide flare of the condyle, for if the flap is too narrow, pressure from the artificial limb may result in impaired circulation. He does not attempt arthrodesis of the patella and feels that it makes no difference whether the patella is allowed to remain or whether it is removed, since, if allowed to remain, it retracts upward out of the way, and, if removed, it requires about one inch extra flap length. Unless length is needed in the anterior flap, therefore, the patella may as well be left. He also points out that the patellar and hamstring tendons tend to fill the intercondylar notch.

Ischial-Bearing Amputations

(More Commonly Termed the Thigh Stump)

Ischial-bearing amputations, as was noted before, are carried out through the middle third of the thigh. The ideal level is between ten and twelve inches below the tip of the greater trochanter, depending on the height of the individual. A stump of this length provides a strong lever arm for propulsion of the prosthesis and leaves the necessary four to five inches of space which is required for the mechanism of the artificial knee. Although this stump does not carry weight upon the bone end, there is, with every step, the up and down piston motion of the stump within the prosthesis, and this results in tension of the skin during each phase of support. It follows, therefore, that skin which is taut over the bone end, or any scar which overlies it or is adherent to it, will be subject to great stress and will in time break down. On the other hand, skin which is too lax will fall in large redundant folds which will hamper the fit and the function of the prosthesis. The flaps covering the bone end should be cut so that their combined length is slightly greater than the diameter of the thigh at the bone level, for this will ensure normal tension, and the anterior flap should be one inch longer than the posterior so that the suture line will fall behind and slightly above the bone end. It should under no circumstances lie upon the ischial tuberosity, which is the weight-bearing point. The healed surgical scar should be thin, short, linear, and free of underlying adhesions. The general shape of the stump should be conical, gradually tapering from above downward.

Although some use a procedure which affords a bone covering of skin alone, I prefer *the following method which places a myofascial flap over the* bone end, for this acts as a terminal insertion for the cut muscles and ensures that they are protectingly grouped about the sides of the bone in its distal portion.

TECHNIQUE

1. *Skin incision.* The anterior incision starts at the mid-point on the medial aspect of the thigh, immediately above the bone level, and passes in a gentle curve, first distally, then laterally, across the anterior aspect, and thence proximally to end on the lateral aspect of the thigh opposite the starting point. The posterior incision originates at the same level and swings convexly downward over the back of the thigh. Both incisions are carried to the depth of the muscle fascia, and the flaps are reflected upward to the bone level.

2. *Section of the soft tissues.* The fascia overlying the quadriceps muscle is divided along the line of the anterior incision, and the underlying muscle is beveled upward to the level of the intended saw line in such a manner that the myofascial flap, thus formed, does not exceed one-half inch in thickness. The posterior fascia is now divided at the level of the incision and reflected upward

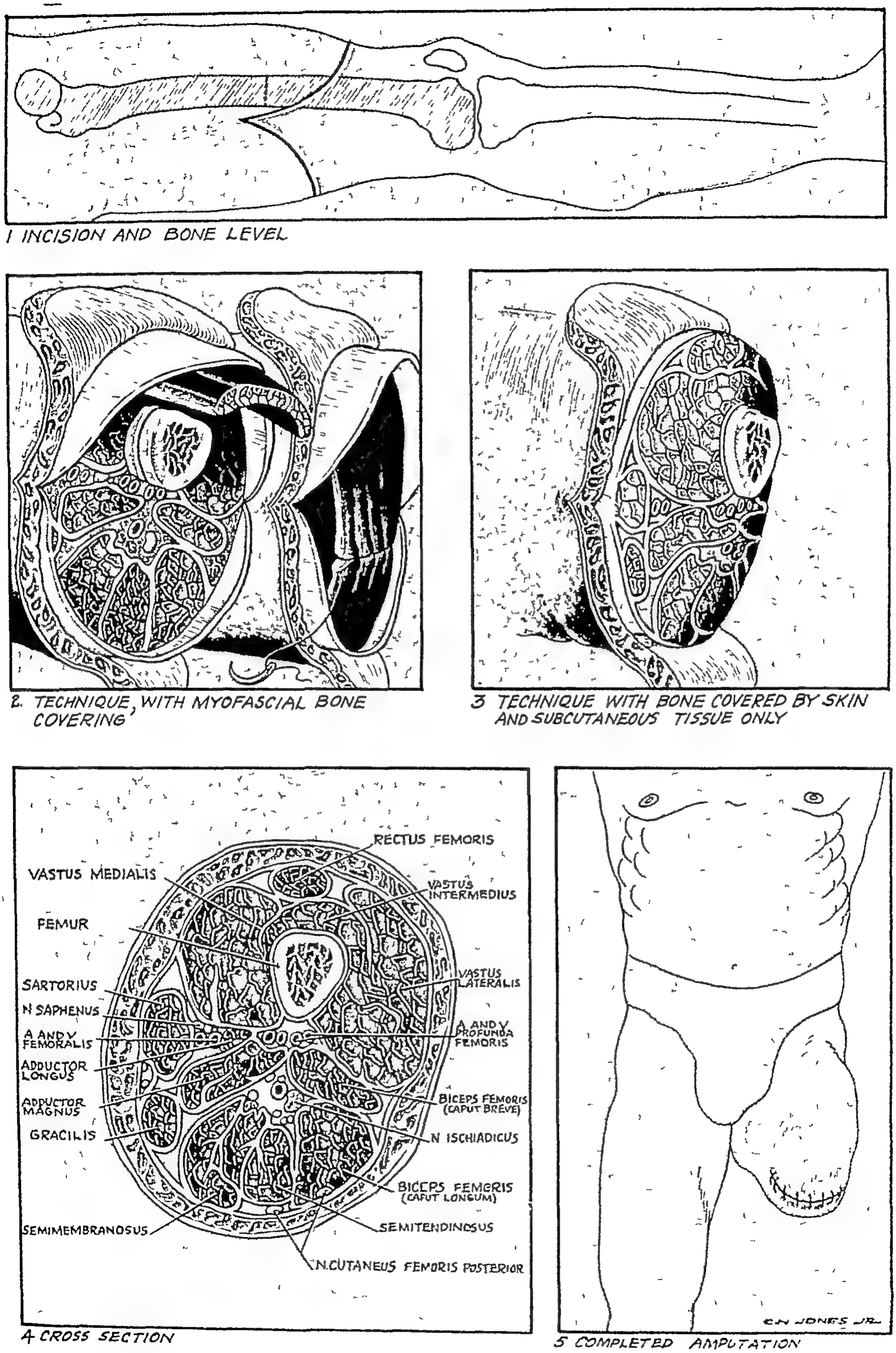


Fig 252 —Amputation of the thigh

The muscles lying beneath it are sectioned transversely so that they will retract to the level of the saw line Long, thin muscles such as the adductor group will retract to a greater extent than the thicker, heavier ones and, therefore, must be divided at a slightly lower level Any excess bulky muscle masses are removed

3 *Bone section* The periosteum is incised circumferentially, and the bone is divided with a saw immediately below it The prominence of the linea aspera is removed, the bone end is smoothed with a file or rasp, especially at its periphery, all loose fragments of periosteum are excised Bone dust is washed from the wound with normal saline

4 *Treatment of the neurovascular structures* The femoral artery and vein lie in the femoral canal, while the profunda femoris lies just behind the bone in the interval between the adductor magnus, biceps femoris, and quadriceps muscles These major vessels are identified, isolated, severed, and doubly ligated with plain catgut The sciatic nerve is identified immediately beneath the hamstring muscle, drawn down gently for an inch or two, sectioned, and ligated The cutaneous nerves are sectioned and allowed to fall back in their beds The tourniquet is removed and hemostasis is completed

5 *Closure* The anterior flap is now drawn down over the bone end Its muscle layer is sutured to the posterior muscle, and its fascial layer is sutured to the posterior fascia In both of these layers if there is any excess or redundant tissue, it is removed after fitting has been determined The skin is now approximated with interrupted skin sutures Drains are inserted near the medial and lateral aspects of the suture line Dressings are applied and the stump is bandaged from the groin to the end of the amputation stump

POSTOPERATIVE CARE The patient is placed in bed with no elevation of the stump being permitted It is dressed at the end of forty-eight to seventy-two hours, at which time the drains are removed The elastic bandage is then reapplied, and the stump is left undisturbed until the end of the fourteenth day unless it is necessary to change dressings because of excessive drainage The sutures are removed at the end of the fourteenth day Elastic bandaging is continued, and the patient is started on stump exercising Fitting of the artificial limb is not allowed until all signs of stump irritation have disappeared

The following *alternate method* of thigh amputation is presented for those who desire a simpler procedure or who feel that the myofascial flap is of no advantage and is possibly a hindrance because of its degeneration into scar tissue It employs an anterior skin flap slightly longer than the posterior, in the ratio of 3 2

TECHNIQUE

1 *Skin incision* The anterior incision starts just proximal to the intended bone level in the mid-lateral aspect of the thigh and swings distally, medially, then proximally, in a tongue-shaped curve, to end at the mid-point of the medial aspect of the thigh at the same level as its point of origin The posterior incision traces a similar, but shorter, arc on the posterior aspect and joins the two ends of the anterior incision These flaps should be carefully formed, so that the anterior one is somewhat narrower than the posterior and its length is equal to three-fifths of the transverse diameter of the thigh at the bone level The length of the posterior flap is equal to two-fifths of the cross section of the thigh at that level The incisions are deepened to the muscle fascia and both flaps are reflected upward

2 *Treatment of soft tissues and bone* The muscle is now divided by beveling it slightly downward to the intended site of osteotomy The periosteum is incised circumferentially, and the bone is sectioned transversely just below the

level of the periosteal incision The linea aspera is beveled, and the bone end is smoothed with a file or rasp so that no rough corners are present The major vessels are isolated, severed, and doubly ligated The nerves are isolated, drawn down, and divided The tourniquet is removed and hemostasis secured

3 *Closure and postoperative care* The skin flaps are approximated by interrupted skin sutures, and a drain is instilled near the lateral end of the wound A dry dressing is used, and elastic bandage compression is applied from groin to stump end The wound is dressed in forty-eight to seventy-two hours and the drain removed The skin sutures are removed on the fourteenth day Compression bandaging is maintained until shrinkage of the stump is complete

AMPUTATION THROUGH THE THIGH ABOVE THE IDEAL LEVEL

To save all possible length is the first fundamental of amputation through the upper third of the thigh Above the ideal level, the shorter the stump is, the greater is the difficulty in maintaining and activating the prosthesis, and the more frequent is the tendency toward flexion contracture When the stump is only three or four inches below the ischial tuberosity and the adductor tendon insertion, the fitting of a prosthesis is very difficult and often quite unsatisfactory, for it is almost impossible to retain the stump within the socket of the prosthesis This is especially true when strong extensor action is applied to force the artificial limb beneath the body, and when the amputee is in the act of sitting The statement has often been made that amputation higher than three inches below the inner aspect of the groin is inferior to that at the trochanteric or hip level I do not agree with this statement In my opinion, even the extremely short thigh stump is to be preferred to hip disarticulation, for the saucer type of socket used in combination with the standard above-knee prosthesis may be worn instead of the heavy, cumbersome tilting table type Although the amputee will lose almost all thigh motion and will have a gait similar to that with the tilting table limb, he will find his artificial member materially lighter and far more comfortable Many individuals, especially in the older age group, would much rather have a thigh amputation at a high level and use crutches, than have a hip disarticulation and use the heavy awkward prosthesis which it requires

Amputation through the thigh at this level should follow the same surgical principles established for the creation of the ideal thigh stump, with one major modification that is, the length of the stump is the primary consideration rather than the ideal skin flaps If bone length can be saved by utilizing skin in other planes, it should be done Experience with open amputation and plastic repair has shown that satisfactory stumps may be obtained at this level with the suture line falling at almost any point It is essential, however, that the muscles be grouped about the end of the bone to prevent protrusion of the bone beneath the skin This is accomplished, of course, by the fascial or myofascial covering over the bone end Fascia lata is an ideal substitute if the anterior fascia is not available The protrusion of the bone beneath the skin, although certainly not a desirable feature, is not in itself an indication for reamputation if the skin is normal and healthy and there is no sign of tissue breakdown

AMPUTATIONS ABOUT THE HIP

This group includes all of those amputations in which the stump must be fitted with a tilting table type of prosthesis, namely, amputation through the trochanters and femoral neck, and hip disarticulation The socket of the prosthesis is shaped in the general form of a quarter hemisphere which is suspended

from above by shoulder straps and held to the body by a pelvic belt. The socket, itself, is contoured to receive the bony prominences of the stump. The greater the extent of the protrusion, the more effectively the socket grasps the stump, and the greater is the control over the prosthesis. It is on this basis that amputation through the trochanters and femoral neck, although more unsightly in appearance than the smooth contoured hip disarticulation, are preferred. Unfortunately elective amputation at this level is usually performed because of malignancy, and the removal of the femoral head is generally required. Whenever possible, the lower levels are used. Weight is borne on the ischial tuberosity, and all scars in that region should be scrupulously avoided. The sensation should be carefully preserved to avoid the occurrence of decubitus in anesthetic skin. The suture line should be placed well anterior so that it will not be affected by pressure and so that the risk of fecal contamination at the time of operation will be decreased. The stump should be well contoured, for if redundant masses of tissue are present, they will be pinched when the prosthesis is worn and the skin folds between them will be subject to intertriginous irritation.

PREOPERATIVE PREPARATION. In addition to the usual preoperative preparation, the patient is always cross-matched for transfusion, and care is taken to insure that adequate blood and plasma are available because of the frequent occurrence of shock. A second precaution is the use of Sulfasuxidine preoperatively to make sure that the pathogens of the intestinal flora are minimal.

Hip Disarticulation

Method of Boyd

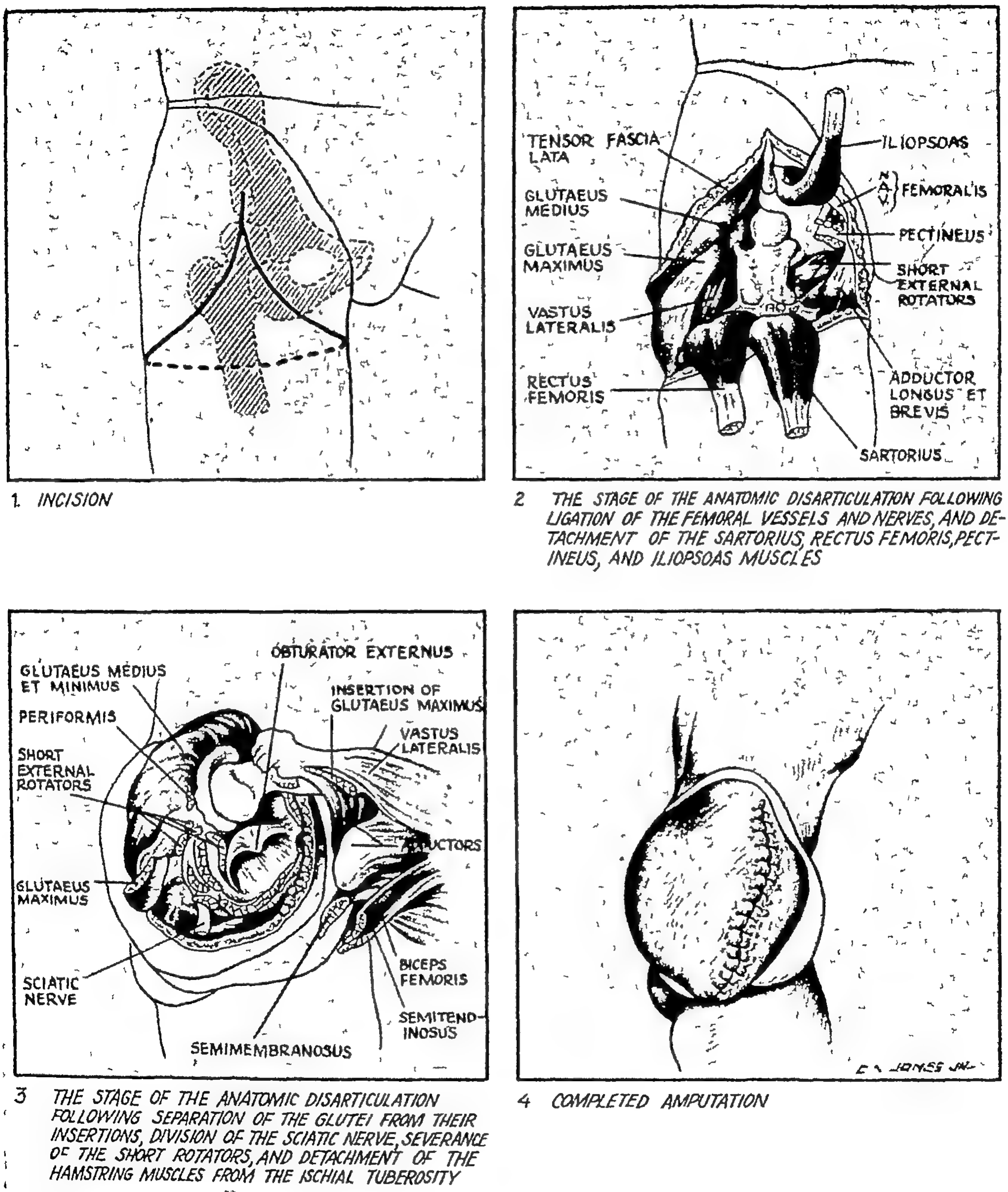
This technique is based on the principle of dissection along fascial planes and division of all muscles through their tendinous insertions to femur and pelvis in order that shock may be minimal and the wound closed without tension. An excellent stump with a large gluteal flap is obtained.

PREPARATION AT OPERATION. The limb is elevated and the blood is expressed by means of an elastic bandage. An Esmarch tourniquet is then applied two inches below the level of disarticulation to prevent the extremity from refilling with blood. This step should be omitted in the presence of active infection, and the bandage should not be wrapped over the site of a malignant tumor. The patient is placed on the unaffected side to permit free movement of the limb at the time of operation.

TECHNIQUE.

1. *Incision.* "A racquet type of incision is employed. Beginning at the anterior superior iliac spine, the incision is curved downward and medially almost parallel with Poupart's ligament, to a point on the inner aspect of the thigh five centimeters below the origin of the adductor muscles. Before proceeding farther, the femoral artery and vein are isolated and ligated and the femoral nerve is injected with Novocain and divided. The incision is then continued around the posterior aspect of the thigh approximately five centimeters distal to the ischial tuberosity, and along the lateral aspect of the thigh about eight centimeters distal to the base of the greater trochanter. From this point, it curves upward, joining the original incision below the anterior superior iliac spine."

2. *Section of soft tissues.* (a) "The sartorius muscle is now detached from its origin at the anterior superior iliac spine and reflected distally, the rectus femoris is detached from the anterior inferior iliac spine and also reflected distally, and the pectineus is divided approximately one-fourth inch from the pubis."



1. *INCISION*

2. *THE STAGE OF THE ANATOMIC DISARTICULATION FOLLOWING LIGATION OF THE FEMORAL VESSELS AND NERVES, AND DETACHMENT OF THE SARTORIUS, RECTUS FEMORIS, PECTINEUS, AND ILIOPSOAS MUSCLES*

3. *THE STAGE OF THE ANATOMIC DISARTICULATION FOLLOWING SEPARATION OF THE GLUTEI FROM THEIR INSERTIONS, DIVISION OF THE SCIATIC NERVE, SEVERANCE OF THE SHORT ROTATORS, AND DETACHMENT OF THE HAMSTRING MUSCLES FROM THE ISCHIAL TUBEROSITY*

4. *COMPLETED AMPUTATION*

Fig 253—Disarticulation of the hip after the method of Boyd (Redrawn from article by Boyd, H B Surg, Gynec & Obst 84 346, 1947)

(b) The thigh is externally rotated, and the lesser trochanter brought into view "The iliopsoas tendon is then severed at its insertion and reflected upward The adductor and gracilis muscles are next detached from the pubis, and that portion of the adductor magnus which arises from the ischium is severed at its origin The plane between the pectineus and the obturator externus and short rotators is delineated and the branches of the obturator artery are ligated The obturator externus muscle is later detached from its insertion into the femur, if the muscle is divided at its origin, the obturator artery may be severed and retract into the pelvis, resulting in hemorrhage difficult to control

(c) "The thigh is internally rotated now The gluteus medius and minimus muscles are detached from their insertions into the greater trochanter, and retracted upward The fascia lata is divided below the insertion of the tensor fasciae latae muscle in the line of the skin incision, together with the lowermost fibers of the gluteus maximus muscle, and the tendon of the gluteus maximus is separated from its insertion into the linea aspera and retracted upward The sciatic nerve is next injected with Novocain and divided The short rotators, of the hip, i e, the pyriformis, gemelli, obturator internus, obturator externus, and quadratus femoris, are divided at their insertions into the femur, and the hamstring muscles are then severed from the ischial tuberosity The disarticulation is now complete except for incision of the capsule of the hip joint near the acetabulum, and division of the ligamentum teres "

3 *Closure* "The disarticulation having been completed, the gluteal flap is brought forward and the distal portions of the gluteal muscles are sutured to the points of origin of the pectineus and adductor muscles The skin is closed *in the routine manner The gluteal flap is sufficiently large to permit closure* without tension A drain is placed in the inferior portion of the incision, to be removed after 24 to 36 hours "

Posterior Flap Method

The procedure utilizes a long posterior-medial skin flap, containing the gluteus maximus, to cover the stump end All muscles are cut at their insertions to minimize shock and bleeding

TECHNIQUE

1 *The incision* The femoral artery is first palpated to locate the starting point of the incision, which arises immediately over it and just one inch distal to the inguinal ligament From this point, the incision passes distally over the medial aspect of the thigh to a point four inches below the pubic tubercle It then swings posteriorly and distally so that a long posterior internal flap is formed Next, it passes laterally and proximally over the posterior aspect of the greater trochanter, and thence anteriorly to reach the starting point of the incision The skin incision is deepened to the muscle fascia It is often difficult to determine the exact length desired for the long posterior flap It is better to err on the side of too much skin, and to trim it to the desired level after disarticulation I use the following method to estimate the amount of skin needed in this flap to cover the bottom of the stump The thigh is flexed to right angles and an imaginary line is drawn parallel with the operating table at a level to pass through the anterior superior spine of the ilium Distal to the point at which this line passes through the posterior aspect of the thigh is added an amount of skin equivalent to the diameter of the thigh at the level of the anterior superior spine when the thigh is flexed

2 *Division of the femoral nerve and vessels* After the skin incision has been completed, the femoral artery is again palpated The femoral sheath is

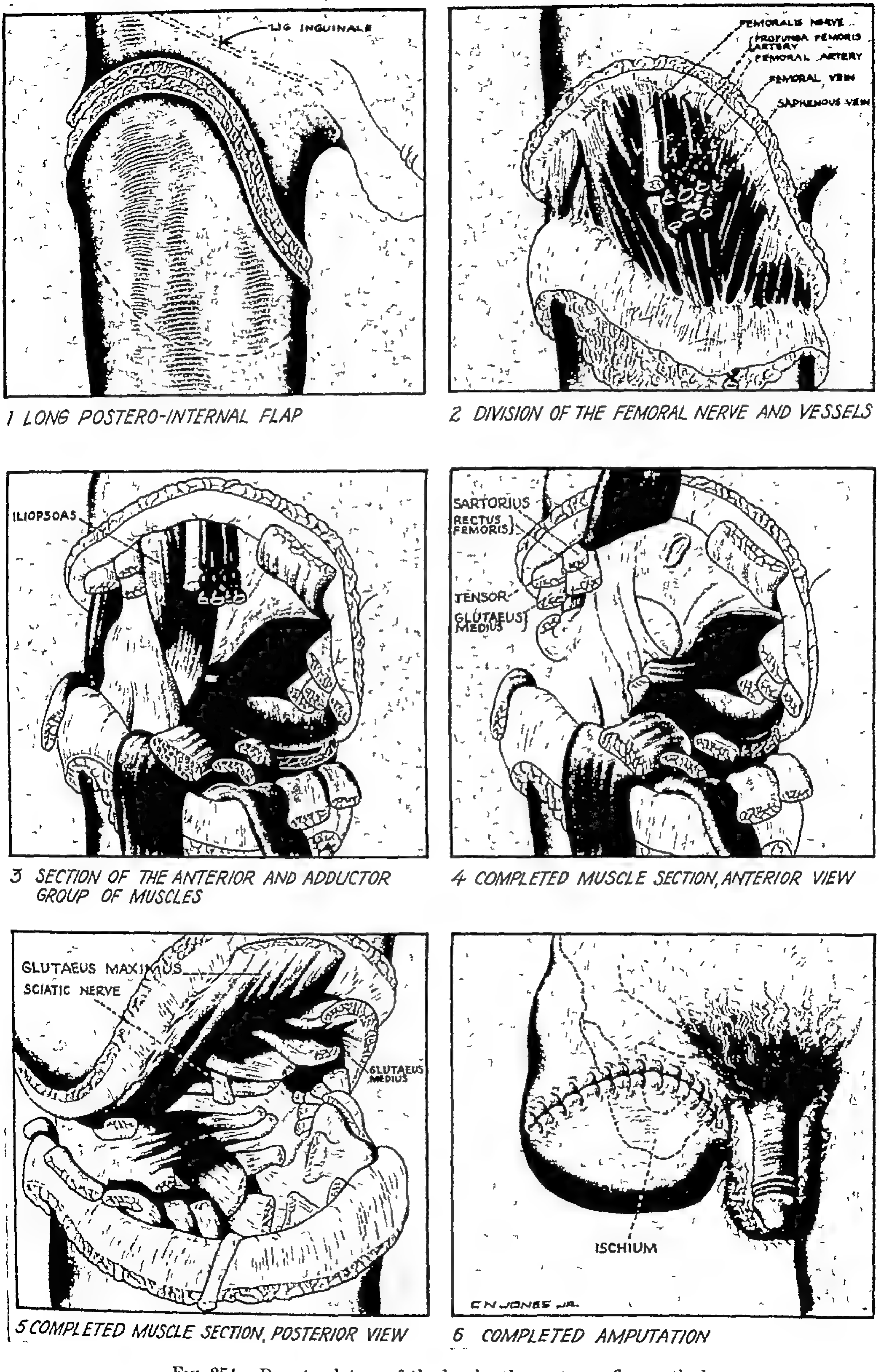


Fig 254 —Disarticulation of the hip by the posterior flap method

exposed by opening the thin covering of the fossa ovalis and distally incising the fascia overlying the vessel The femoral artery is doubly ligated, preferably above its bifurcation, and the femoral and saphenous veins are clamped and doubly ligated The femoral nerve which lies immediately lateral to the femoral sheath is isolated, drawn down, and cut so that it will fall above the inguinal ligament Some surgeons prefer to make a separate incision above the inguinal ligament and section the femoral nerve by intrapelvic approach

3 *Section of the soft tissues* The thigh is placed in wide abduction to tense the muscles on the inner aspect of the thigh All adductor muscles are now sectioned at their pubic insertions Care is taken to isolate the two branches of the obturator nerve as they lie above and below the adductor brevis These two nerves are sectioned in such a manner that they will retract upward away from any pressure of the prosthesis The sartorius and rectus femoris are next sectioned at their attachments from the anterior superior spine The thigh is now placed in slight adduction and internal rotation The tensor fasciae latae is sectioned at the level of the greater trochanter The muscles attaching to the greater trochanter are severed close to the bone, these include the gluteus medius, the gluteus minimus, obturator internus and externus, and the pyriformis muscle The thigh is placed in further adduction, and the gluteus maximus is sectioned at the distal end of the skin flap and allowed to fall posteriorly The sciatic nerve is isolated, drawn down, ligated, and sectioned high (This step is often accompanied by shock, and for this reason some surgeons prefer to inject the nerve with Novocain prior to section) The hamstring muscles are now sectioned near their pelvic attachments

4 *Disarticulation* The capsule and ligaments of the hip joint are sectioned circumferentially The hip is dislocated, and the ligamentum teres is sectioned to complete the severance of all structures joining the thigh to the pelvis The leg is discarded All ligamentous tissue is débrided from the acetabulum The acetabular rim, itself, need not be disturbed

5 *Closure* A test fit of the long posterior flap consisting of gluteus maximus and skin is now made To collapse the dead space, the acetabulum is filled with muscular tissue, the iliopsoas muscle being the most convenient, all excess muscular tissue in the gluteus maximus is trimmed away, the skin is tailored so that anatomic approximation may be carried out without tension at the suture line Absolute hemostasis is secured, no bleeding points being allowed to remain, and the flap is fixed with interrupted skin sutures A drain is inserted at the lateral aspect of the wound Dry dressings are applied and fixed with a spica of elastic bandage

Postoperative Care The wound is dressed after forty-eight to seventy-two hours, and the drain is removed The stitches are removed on the fourteenth postoperative day Compression with an elastic bandage spica is continued until maximum shrinkage has been obtained

HINDQUARTER AMPUTATION

This radical amputation is indicated only in instances of malignant tumor where complete removal of the lower extremity by hip disarticulation is not sufficient to eradicate the disease The patient should be under careful observation to detect whether there are metastases, and to gauge his ability to withstand such a major procedure Even then, it should only be undertaken by a skilled surgeon Operative shock may result from blood loss, prolonged operating time, rough handling of the tissues, section of the major nerve trunks before injection with Novocain or change in position during surgery The patient should al-

ways be warned before operation that a prosthesis may not be practical Synonyms for this procedure are inter-innomino-abdominal amputation, inter-ilio-abdominal amputation, transiliac amputation, transpelvic amputation, and hemipelvectomy

PREOPERATIVE PREPARATION The patient is given the usual orthopaedic preparation The large bowel is cleansed by enema the night before the operation and the morning of amputation The bladder is catheterized in the operating room The patient is typed for transfusion, and 1,000 c c of blood should be available in the operating room Before the operation is started, a large transfusion needle is placed in the vein so that blood can be administered whenever necessary The blood within the limb to be amputated may be conserved by use of a tight compression bandage from the toes upward to the mid-thigh

Method of King and Steelquist

The two salient features of this method of hip disarticulation are (1) the removal of the pelvis by disarticulation at the symphysis pubis and section of the posterior portion of the ilium near the sacroiliac joint, together with the severance of soft tissues connecting the trunk with the extremity, and (2) the formation of a large *gluteal flap,* made up of skin and the gluteus maximus, which is swung anteriorly to meet the skin and muscles attached to the upper portion of the pelvic brim The operative technique of transiliac amputation must be modified to meet the requirements of each individual case The operation may be divided into three parts (a) the anterior stage, (b) the perineal stage, and (c) the posterior stage It is performed in the full lateral position

INCISION The skin incision begins at the pubic tubercle near the symphysis and extends proximally and laterally along the inguinal ligament to the anterior superior spine, and then posteriorly along the iliac crest to the posterior superior spine The perineal portion of the incision is carried out with the leg widely abducted The incision is carried from the pubic tubercle laterally, and then posteriorly along the pubic and ischial rami to the ischial tuberosity The posterior portion of the incision, which forms the large flap of skin and muscle, starts at the posterior superior spine and passes anteriorly and slightly distally to the greater trochanter At this point, it turns posteriorly to follow the gluteal crease to the ischial tuberosity where it joins the perineal portion of the incision The incision is carried out piecemeal as each stage of the operation proceeds

a *Anterior stage* The skin incision, which at this stage is carried from the pubic tubercle to the mid-lateral aspect of the ilium, is deepened to bone Laterally, the abdominal muscles and inguinal ligament are detached from the iliac crest, and the iliac fossa is deepened between the peritoneum and iliacus Medially, at the pubis, the inguinal ligament and rectus abdominus tendon are severed The spermatic cord is now retracted medially and the space of Retzius opened The bladder is retracted medially to afford wide exposure The external iliac artery and vein are now located, cut, and doubly ligated The femoral nerves are injected with Novocain and divided cleanly with a sharp knife The precaution of placing a rubber-shod clamp temporarily on the common iliac artery during the operation, with the idea of controlling hemorrhage from its branches, is not really necessary The anterior wound is now tightly packed with dry gauze

b *Perineal stage* The perineal portion of the incision is deepened to bone as it passes from the pubic tubercle along the pubic and ischial rami to the ischial tuberosity The superficial portion of these bones is now exposed The interior surfaces are quickly denuded by subperiosteal elevation of the ischiocavernosus

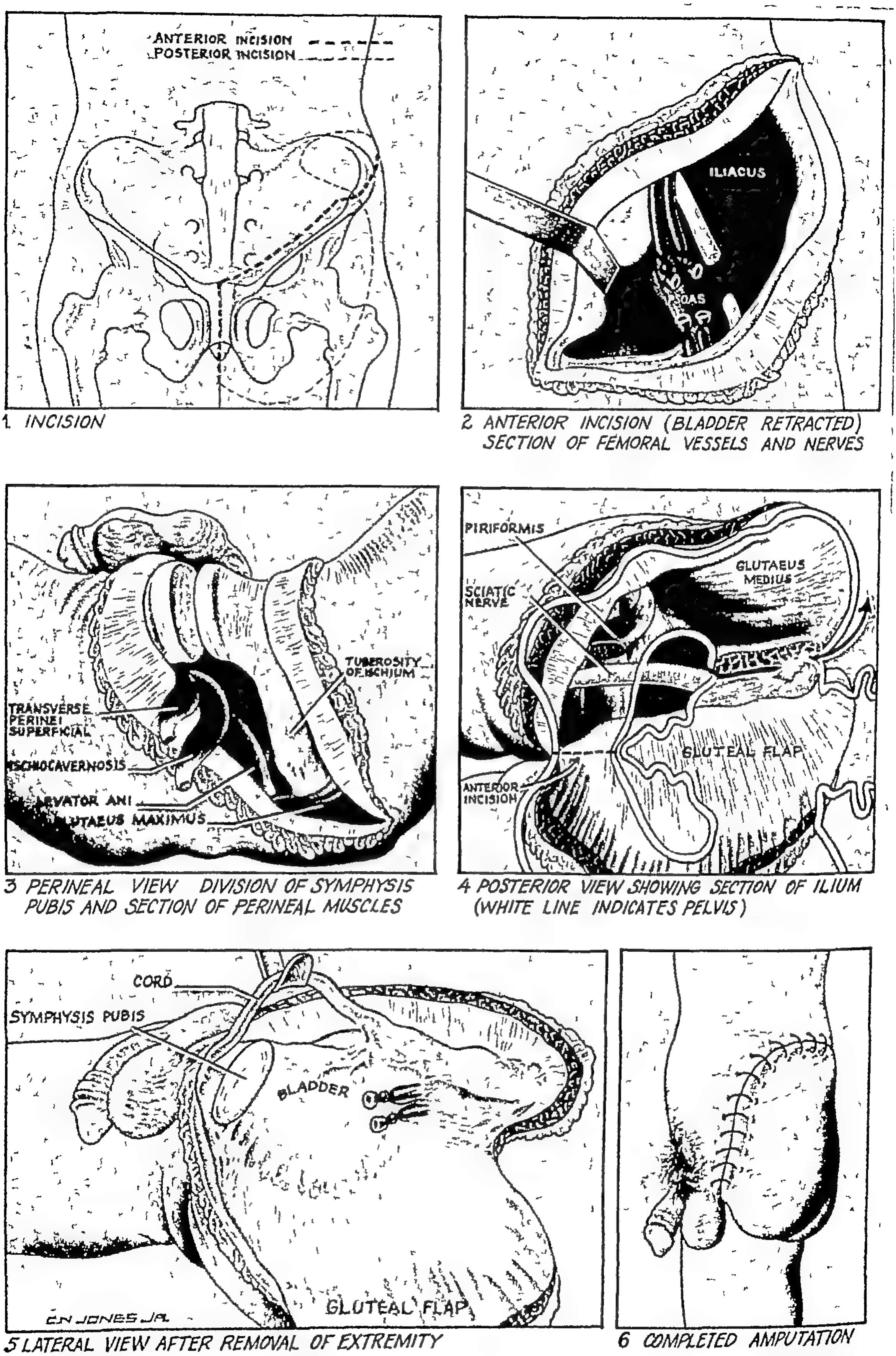


Fig 255—Hindquarter amputation after the method of King and Steelquist

and transversus perinei. The symphysis pubis is divided by section of the ligaments and fibrocartilage of the synchondrosis with an osteotome.

c. *Posterior stage.* Here, the posterior portion of the iliac crest is exposed by carrying its overlying skin incision to bone. The incision which swings anteriorly and distally from the posterior superior spine to pass over the greater trochanter and then turn posteriorly along the gluteal fold to the ischial tuberosity, is now deepened along the line of the skin incision to section the fibers and aponeurosis of the gluteus maximus at its posterior and inferior edges. This large posterior flap contains skin, fat, and gluteus maximus. It is now reflected outward to expose the gluteus medius and rotator muscles of the hip, and the sciatic nerve. The pyriformis is severed. The sciatic nerve is tied, injected with Novocain, and sectioned cleanly. A Gigli saw is now passed anteriorly through the greater sciatic notch, over the anterior surface of the ilium just in front of the sacroiliac joint, then backward over the iliac crest, the posterior ilium is divided. Following division of the posterior ilium, the sacrotuberous and sacrospinous ligaments are severed. The innominate bone is now freely movable and will rotate with the lower extremity to give wide intrapelvic exposure. The obturator vessels and nerves are ligated and divided. The psoas muscle is cut at the level of the sacroiliac joint. The levator ani muscle is now sectioned close to its origin on the pubic bone to free the lower extremity completely.

d. The wound is closed by drawing the gluteus maximus flap anteriorly and suturing it to the rectus abdominis, lateral abdominal, the quadratus lumborum, and the psoas muscles. Three or four soft rubber tissue drains are inserted into the wound and the skin is closed loosely. The drains are removed after forty-eight to seventy-two hours. Dry dressings are applied to the wound, and they are fixed by means of an elastic bandage and adhesive tape. The patient is given blood and fluids in accordance with his postoperative condition, and then placed on a liquid diet for a period of one week to eliminate the necessity for bowel movement.

Method of Sorondo and Ferré

The method of hip disarticulation presented by Sorondo and Ferré consists of (1) removing the pelvis and its attached limb after disarticulation of the symphysis pubis, section of the sacrum near the sacroiliac joint, and division of the soft tissues, and (2) then swinging a large posterior *skin flap* anteriorly to meet the skin of the upper portion of the pelvic brim. Two surgeons operate simultaneously.

Position—full lateral position with the normal side down. A rope and pulley are attached to the ankle from above so that the involved part can be manipulated by an unsterile assistant.

TECHNIQUE

1. *The incision.* The limb is placed in 30 degrees abduction. The upper limb of the incision starts just medial to the posterior superior spine of the ilium and passes anteriorly, then medially, parallel and 3.0 cm. below the crest of the ilium and Poupart's ligament, to the pubis. The medial portion of the incision crosses the inner aspect of the thigh 3.0 cm. below the perineum. The posterior limb of the incision starts just lateral to the posterior superior spine and passes distally and laterally over the greater trochanter and then curves to swing posteriorly and medially following a course of 3.0 cm. below the gluteal fold to join the perineal portion of the incision.

2. *The anterior approach.* With the limb abducted 30 degrees, the anterior and lateral abdominal muscles and the ilioinguinal ligament are detached from the pelvic brim to expose the peritoneum and retroperitoneal tissues. These

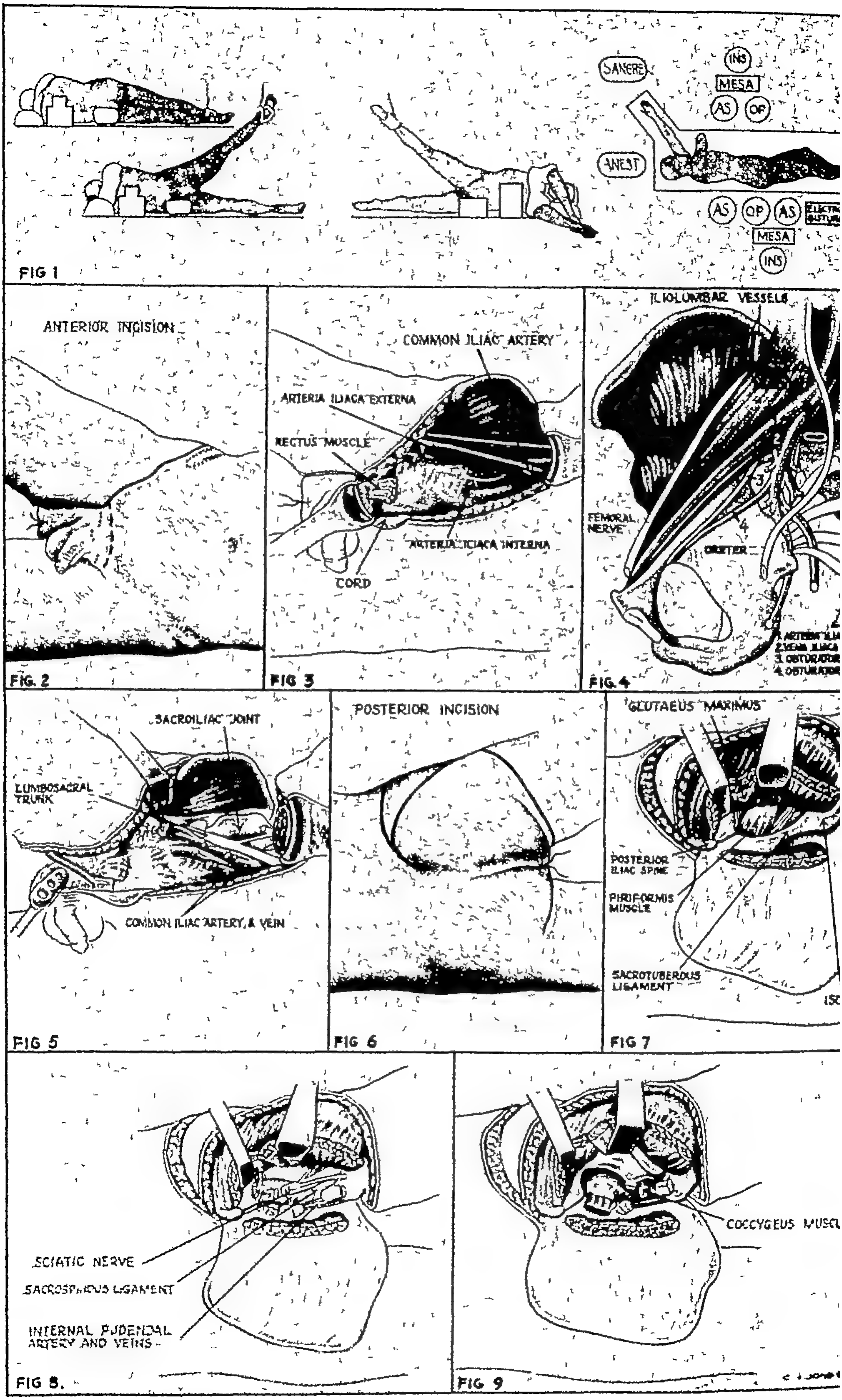


Fig. 256.—Hindquarter amputation after the method of Sorondo and Ferré. (Redrawn from paper presented by J. P. Sorondo and R. L. Ferré at the Inter American Congress of Surgery, Montevideo, 1946.)

structures, including the bladder, ureter, spermatic and ovarian arteries, rectum, and uterus, are retracted medially These structures should be handled gently to avoid postoperative ileus The anterior aspect of the sacroiliac joint is exposed by section of the soft tissues overlying it in the following order (1) external iliac artery, (2) psoas muscle, (3) femoral nerve, (4) obturator nerve, (5) obturator artery, (6) external iliac vein, (7) iliolumbar vessels The superior and inferior gluteal and internal pudendal vessels are divided and ligated, freeing the hypogastric artery and vein together with the lumbosacral plexus, so that they may be retracted medially The dissection now proceeds to the anterior aspect of the pelvis, where the corpus cavernosum is stripped from the inferior ramus of the pubis and the remaining soft tissues are stripped away from the symphysis The symphysis is then divided by a Gigli saw

3 *The posterior approach* The posterior skin flap is reflected medially The posterior brim of the pelvis is now cleared by dissection of the lateral abdominal muscles from the crest of the ilium The dissection proceeds posteriorly, clearing the posterior iliac spine and sacrum by division of the sacrospinalis muscle, iliolumbar ligament, and gluteus maximus The latter structures are reflected out of the field to expose the sciatic notches The superior and inferior gluteal vessels are identified and sectioned at a point well away from the pyriformis muscle, for, if divided close to it, they tend to retract within the pelvis where bleeding is very difficult to control The pyriformis muscle is divided near the sacrum The sciatic nerve, the posterior cutaneous nerve of the thigh, and the sacrotuberous ligament are now divided The pudendal vessels which supply the corpus cavernosum are preserved The sacrospinous ligament is sectioned and the corpus cavernosum and urogenital diaphragm freed from the inferior ramus of pubis and ischium Under the direct vision of the anterior and posterior surgeons, the levator ani and coccygeus muscles are sectioned

4 *Section of the sacroiliac joint* The anterior surgeon passes a Gigli saw over the sacrum to the posterior surgeon who sections that structure near the sacroiliac joint The amputated limb is now freed from the trunk by section of any remaining soft tissue bands and withdrawn from the field

5 *Closure* The posterior skin flap is brought over the wound and approximated to the anterior incision with interrupted sutures Drains are used A dry dressing is applied under moderate pressure and sealed off from the rectum with tape

Postoperative Care The patient is given shock therapy on the operating table if this is necessary and is given laudanum if he has the urge to move his bowels during the first two postoperative days Drains are removed in twenty-four hours The bowels can be moved on the third day this can be expedited on the fourth or fifth days by a gentle rectal irrigation and the use of Prostigmine Stitches are removed on the eighth day, and the patient is allowed to be up and about on the tenth day

PART 4

THE CONVALESCENT PERIOD

VII. INTRODUCTION

Every effort at the time of surgery has been turned toward the creation of the good stump: the most functional length has been obtained, the scar has been placed where it will be least subject to irritations, nerves have been treated so that the likelihood of pain will be least, and the muscles and other soft tissues have been tailored to prevent redundancy and ensure ideal form. With the closure of the surgical wound, convalescence begins, and from that time onward the attention of the physician is directed toward the preservation of these qualities and the preparation of the stump for future usefulness, as he concerns himself with the recovery and rehabilitation of the amputee. Throughout the entire period careful observation is made for the sequelae of surgery, misdirected treatment, and misuse or abuse of the stump by the patient, and steps are taken for the timely correction of any such complications.

In the early convalescent or immediate postoperative period, treatment is directed toward obtaining sound wound healing and preventing contractures, and in general it follows the care accorded the usual surgical case. Amputation surgery, however, is at best a severe procedure and the operative trauma of cross-section surgery evokes tissue reaction far in excess of that normally attending dissection between tissue planes. For this reason the surgeon takes additional care to provide tissue rest and control the inevitable edema by wrapping the stump, immediately after closure, with an elastic compression bandage and, if necessary, placing it in a plaster splint. While the compression dressing is necessary and desirable, its application is not without its dangers. If it is applied unevenly, or too snugly, constriction of the soft tissues may be sufficient to cause the circulatory embarrassment and swelling attendant on the impairment of return venous flow, and if adequate padding is not provided over bony prominences, pressure sores may result. In addition, unequal compression may distort the shape of the stump, and immobilization of the joints in malposition may give rise to adaptive shortening of the soft tissues and subsequent contracture. It cannot be emphasized too strongly that the bandage must be applied correctly if future complications are to be avoided. It should be wrapped smoothly and evenly under moderate tension and preferably over several layers of sheet wadding; the turns should be oblique, never circular, in order that they may not constrict the vessels; equal pressure should be exerted throughout to mold the stump evenly and to prevent "window edema"; and wrapping should be carried upward over the joint proximal to the stump, both to fix the bandage and to maintain the joint in a functional position so that contracture and joint immobility may not ensue.

With further regard to the prevention of contractures, it is essential that the patient assume proper bed posture from the time that he returns from the operating room throughout the period of enforced bed rest The joint above the amputation stump should lie in the neutral functional position and splints should be utilized, if necessary, to maintain it Pillows should never be placed beneath the stump, as is so often done following thigh or below-knee amputation through the misguided enthusiasm of those seeking to ensure the comfort of the patient

A word should be interjected here concerning skin traction After final closure it is but rarely indicated, in fact, in most instances it is undesirable If the skin has been sewn under normal tension, traction will be unnecessary, and, if applied, will be likely to overpull the skin and draw it too far distalward so that accurate approximation of the wound edges will no longer be maintained All too commonly, infolding, splitting, and irritation of the skin about the suture line result from such a procedure If the skin has been sewn under excessive tension, traction will rarely remedy the situation, but, usually in spite of it, the wound will break down or will heal by broad unserviceable scar, and later revision of the stump will be required

In late convalescence when the wound is soundly healed (a minimum of three to four weeks following surgery), measures are taken to mold and strengthen the stump and build up the body as a whole, and the patient is instructed in proper stump hygiene Treatment now lies largely within the field of physical medicine and consists of continued bandaging, massage, and therapeutic exercises Bandaging is carried out as before, but now with the objective of preventing dependent edema as the patient is ambulatory on crutches, and of molding the stump evenly that it may be fitted readily by the socket of the artificial limb Massage, or hydromassage in the form of whirlpool therapy, is utilized to mobilize the surgical scar from the underlying tissues and rid the stump of tenderness, and to improve vascularity, thereby eliminating edema and bettering the tone of the skin and subcutaneous tissues But it must be prescribed judiciously it should never be used until the wound is judged to be soundly healed, lest breakdown and secondary ulceration result, and it must never be undertaken where subclinical infection is suspected because of the readiness with which it reawakens latent infection The skin, which tends to become ischemic, toneless, and atrophic because of the prolonged bandaging, derives particular benefit from massage, but care must be taken to ensure that it is not softened in the process, for it must be thoroughly dry and tough if it is to be resistant to infection and stand up under use within the prosthesis For this reason, lubricants should not be used either during or after treatment, and whirlpool baths should not be of more than fifteen minutes' duration, especially if the water is warm If a toughening agent seems indicated, alcohol is probably the best, for it both toughens and dries the skin (Strong astringents and commercial skin tougheners of unknown composition should be avoided) About the end of the stump, toughening may be further encouraged and tenderness eliminated by tapotement, which is gradually increased as the stump becomes more resistant In the end-bearing stump, preprosthetic weight-bearing may be carried out with the same objective by placing the stump upon a stool, which is padded (several folded towels will serve) and of suitable height and superimposing the weight upon it, at first gently and then with gradually increasing intensity as tenderness diminishes Therapeutic exercises for the muscles of the amputated extremity are carried out during this period to prevent and eliminate contractures by promoting muscle balance and mobilizing the joints They should be guided by periodic muscle checks to ensure that the

dominant muscles are not overstrengthened in relation to the weaker ones Exercises for other parts of the body are prescribed for general conditioning and to restore the normal body mechanics and prepare the patient for the use of the artificial limb For the lower extremity amputee, they include general postural, balancing, and coordination exercises, for the upper extremity they consist of general postural, shoulder abduction, and general muscle strengthening exercises In the latter, particular attention is given to a remaining normal minor arm, which must assume many of the tasks of the major arm even though a prosthesis is worn, occupational therapy is employed, in conjunction with physical medicine, to promote the future usefulness

In the final phase of convalescence, when the stump is deemed fully prepared, the prosthesis is introduced, the amputee is trained in its use, and the course of amputation surgery draws to a close

The succeeding sections of this text are devoted to a more detailed discussion of the considerations of the convalescent period the diagnosis and correction of complications which may arise, the selection and fitting of the prosthesis, and the therapeutic measures and the training methods employed to rehabilitate the amputee and return him to normal life

Stump Hygiene

The patient should be instructed in proper stump hygiene, that is, the general care of the stump and of the stump sock, for it is the best prophylaxis against the minor complications such as dermatitis and skin irritations The stump should be kept thoroughly clean It should be washed daily with a bland, nonmedicated soap and water, and should then be exposed to the air and sun whenever possible In dry, cold climates, where severe chapping is likely to follow the frequent and thorough washings, a superfatted soap, or soap substitute, may be used, but, in general, greasy or oily substances should be avoided since their use predisposes to folliculitis (Herold) Alcohol should not be used once the skin has become toughened and returned to normal, because of its dehydrating effect As for the stump sock, it is a vital accessory which is always worn with the conventional artificial limb and is designed to absorb perspiration, prevent irritation of the stump from chafing, and help preserve the cleanliness of the socket If it is correctly fitted and properly cared for, it contributes materially to the health of the stump and the comfort of the wearer of the prosthesis It should fit snugly about the circumference of the stump, as any looseness may cause wrinkling and subsequent irritation, it should have some slack at its lower end to relieve tension at that point, and it should be folded down over the top of the socket or corset to prevent slipping

Following are the measurements taken to determine the correct size of the sock and a few guides as to its care

Measurements of the stump sock The circumference of the distal end of the stump, the circumference of the upper rim of the socket or corset, and the length of the stump from its distal end to just above the upper rim of the socket *To the length is added two inches, so that the sock can be turned* down over the top of the socket or corset

Care of the stump sock Since perspiration and dirt on the stump tend to cause irritation to the tissues and possible breakdown of the scar, cleanliness of both stump and sock is imperative The sock should be changed every day, and when excessive perspiration occurs (as in hot weather) more frequent changes may be necessary The application of talcum powder to the stump aids in absorbing perspiration and prolongs the length of time the sock may be worn

The sock is usually made of pure virgin wool, but cotton may be used by those who are allergic to wool or cannot tolerate it for some other reason The wool sock requires very careful laundering A mild soap should be used, and both wash water and rinse water should be lukewarm The sock should not be rubbed, but first soapy water and then rinse water should be squeezed through it It should be rinsed several times (This is important in the care of the cotton stump sock also) The water should be squeezed, not wrung, from the sock To dry, the sock should be spread out flat with the open end hanging down, or should be placed on a sock stretcher so that its shape and texture will be retained during the drying process and no shrinkage will occur to lessen its size

VIII. COMPLICATIONS OF THE FINAL AMPUTATION STUMP

Complications do arise in the final, closed amputation stump sometimes despite meticulous observance of the considerations and surgical techniques thus far discussed, sometimes for lack of knowledge or application of them No matter what their antecedents, they are a serious development in amputation surgery, for anything which impairs the future utility of the stump, or any factor which delays the recovery of the amputee or removes him from his prosthesis is of tremendous importance to his physical well-being and his psychological outlook toward eventual social readjustment

Postoperative Breakdown of the Wound

The failure of the wound to heal normally following surgery is usually the result of **postoperative hemorrhage, infection,** or **errors in surgical technique** The final outcome of such failure will be either (1) an open, draining or granulating wound which will not be compatible to the use of a prosthesis, or (2) a wound healed by broad, deep cicatrix, fixed to underlying tissues and restricting skin mobility, which will break down with the piston action of the prosthesis or will cause pain because of tension on the deeper tissues Should wound healing fail to take place per primam, every effort should be made to determine the source of trouble and to eradicate or correct it promptly

Postoperative bleeding may be of two types massive bleeding, or general oozing from the sectioned surfaces Spontaneous massive hemorrhage should be suspected by the sudden onset of pain, accompanied by swelling within the stump The swelling is often not recognizable if the stump is wrapped snugly with elastic bandage compression, but when this is removed, there is usually little difficulty in recognizing the condition Such bleeding results when the ligature has slipped from a vessel and the terminal thrombus has been lost or when a vessel has not been ligated at the time of surgery It is not uncommon for it to result also from early postoperative trauma, the most usual example of which is when the patient, in a half-waking condition, steps out of bed and, forgetting that his leg is missing, falls upon the stump as he attempts to put weight upon the extremity Whatever the cause of hemorrhage of this type, the operative wound should be opened, the bleeding vessel ligated, and closure reeffected immediately Packing and compression dressings are rarely successful in such an instance, and the delay incurred by their use serves only to increase the friability of the tissues, the liability of infection, and the probability of wound breakdown The formation of hematomata due to generalized oozing from the cut surfaces of transected tissues may occur despite the most diligent hemostasis, the most careful elimination of dead space, the use of drains, and the application of pressure dressings It is evidenced by edema and fluctuation beneath the skin of the stump, and its early recognition is the key to successful

treatment. Once it is diagnosed, the fluid accumulation should be removed either by opening the wound and evacuating the blood, or, preferably, by aspirating it through normal tissue adjacent to the suture line. A pressure dressing should then be applied to forestall further bleeding.

When **infection** develops within an amputation stump, a prolonged postoperative course may be anticipated, and there is always the possibility that reamputation may be necessary to obtain a satisfactory stump. Because of the seriousness of even minor sepsis, every effort is made preoperatively to eliminate all conditions conducive to infection of skin, bone, and soft tissues: when time permits, the patient is built up to a point where he will have the greatest possible resistance to infection, and chemotherapeutic drugs are routinely used in prophylaxis. At operation, equal effort is made to avoid creating a pabulum of serum and traumatized muscle in which pathogenic bacteria thrive, by delicate handling of the tissues, careful hemostasis, and accurate approximation of the wound. Postoperatively, compression dressings, splinting, and postural drainage through elevation (except in the thigh where flexion contracture may develop) are routinely used. In spite of the most diligent care and observation, infection in one manifestation or another may occur, and it is its early recognition and treatment that will save the stump from extensive involvement with loss of skin and valuable bone length.

Cellulitis is a diffuse infection, usually streptococcic in origin, which most commonly involves the entire end of the stump. The affected area is warm, tender, swollen, and varies in color between a dull red and bright pink. The temperature is elevated, and the patient is toxic. Since the involvement is diffuse rather than localized, operative interference is not indicated. The treatment consists of the application of hot packs, elevation of the stump, and the administration of chemotherapeutic drugs—sulfonamides if the sepsis is of hemolytic streptococcic origin, penicillin in all other instances. It should be undertaken promptly, for local tissue destruction or diffuse fibrosis of the tissues will take place rapidly.

Osteomyelitis is rarely hematogenous in origin, but is almost always the result of the flare-up of an old infected area in the bone, the reactivation of a latent infection near the bone, or the invasion of pathogenic bacteria through the wound. With such an etiology its occurrence in amputation surgery, as might be anticipated, is most frequent following the final repair of an open amputation. It may lie deep within the stump where quiescent infection within scar tissue of the medullary canal, along the course of a healed fracture or about an undiscovered foreign body, has been reactivated by the trauma of surgery, despite the most gentle handling, or it may be limited to the end of the stump where the sepsis has entered through the portals of the open wound and has manifested itself in local abscess and sinus tract formation. In any instance the extent of involvement depends upon the virulence of the organism, the resistance of the host, and the dispatch and efficiency with which the condition is discovered and treatment instituted. Treatment consists of wide-open surgical drainage with removal of all sequestra, foreign bodies and necrotic bone and soft tissue. Temporization by the use of hot packs, chemotherapy or minimal surgical drainage is inevitably doomed to failure, since only adequate wide-open drainage of soft tissue and bone will rid the stump of this type of infection. When the wound is healed and free from sepsis, secondary plastic repair or revision is the rule.

Deep soft tissue abscess within an amputation stump may arise either from the entry of pathogenic organisms through the portal of the wound, or from the

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Fig 257—Severe infection of a below knee stump Onset on the sepsis was on the second postoperative day, and removal of all sutures and establishment of wide open drainage was required Loss of valuable stump length is inevitable when final closure is again undertaken

Fig 258—Postoperative breakdown of a Syme amputation Drainage was instituted and reamputation at a higher level was later required Note the large area of skin slough (Walter Reed General Hospital Neg No 4669 2)

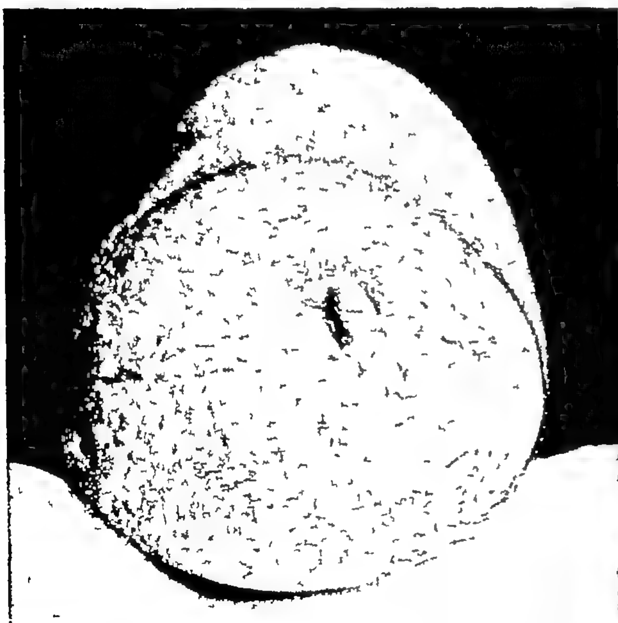

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Fig 259—Deep soft tissue abscess with spontaneous rupture through the end of a below-knee stump Wide drainage was required (Walter Reed General Hospital Neg No 4595 3)

Fig 260—Stitch abscess with slough of the skin at the wound margin Cleansing of the granulation was followed by plastic repair

Fig 261—Reactivation of osteomyelitis following final repair of a thigh amputation, with breakdown and drainage through the end of the stump Wide open drainage and sequestrectomy were required (Walter Reed General Hospital Neg No 4397-2)

Fig 262—Sinus tract coming on following final surgery, treated by wide incision This case was first treated to no avail by hot packs, Dakin's irrigation, and chemotherapeutic drugs When the sinus was finally incised to its origin, a foreign body was found This was removed, the granulations were curreted from the walls of the tract, and a petrolatum pack was placed in the wound Whirlpool was later used to clean the wound (Walter Reed General Hospital Neg No 4558-2)

reactivation of a quiescent focus of infection within the soft tissues It is particularly prone to occur about foreign bodies of the organic type, and in areas of diminished circulation caused by excessive scarring, peripheral vascular disease, or crushing injury For deep soft tissue abscess massive, hot, wet packs should be applied until localization has occurred, and then surgical drainage should be carried out immediately by wide incision Small stab wounds are totally inadequate in the drainage of stump abscess and lead to the formation of sinus tracts or deep inverted scars Since it is only the unusual case which does not require a secondary plastic procedure following the drainage of the soft tissue abscess, there is no reason to hesitate to open the infected area widely for drainage and at the same time make a careful débridement of necrotic elements and removal of foreign bodies

Stitch abscess, in contrast to deep soft tissue abscess, is usually localized to the skin When sutures are under tension because of operative technique or postoperative swelling, the needle hole will gap slightly and a serous ooze will develop If bacteria have been imbedded in the skin at the time of placement of the suture or have passed along the course of the suture at a later time, they will find nourishment within this serous ooze, and the result will be signs of local inflammation and eventual abscess This is more likely to occur about the cotton and silk sutures than about the metal because of their capillary or "wick" action A stitch abscess can usually be controlled simply by removing the suture, though warm, wet packs are occasionally required

The *sinus tract* is one of the most troublesome of all infectious processes following surgery It originates about a focus of infection several inches above the end of the stump and burrows through the soft tissues, following the fascial planes in the line of least resistance, to appear as a small opening at the end of the stump or near the surgical wound It is lined throughout with granulation tissue on a base of scar, and contained within its upper end is the focal point, which may be an osteomyelitic area, sequestrum, retained foreign body, nonabsorbable suture, or old abscess cavity It is useless to attempt conservative treatment of sinuses by means of hot packs, irrigation, or antibiotic drugs, since these measures fail to eliminate the nidus of infection and the pyogenic membrane Rather, surgery should be employed immediately to lay the sinus open from origin to outlet, and to remove all granulation tissue and the focus of infection Although an occasional small open wound thus created will be satisfactorily healed by scar, it is the general rule that most will require plastic repair and should be accordingly prepared the wound is kept packed until new granulations form and these are then cleansed with saline packs until they appear firm and healthy, when this stage is reached, the scarred bed is eradicated by block excision to the level of normal, healthy, bleeding tissue, and the marginal skin is resected to a point where it is normal, soft, and pliable Plastic repair is then effected in accordance with the technique used in the final repair of the open amputation

Anaerobic infection very rarely occurs in the final amputation stump because of the surgical elimination of all necrotic and avascular tissue prior to closure, and the routine use of penicillin It may be seen upon occasion, however, when débridement of the open amputation has been inadequate It is evidenced by crepitation beneath the skin, thin watery discharge, characteristic odor, and general toxemia From the viewpoint of treatment in the final amputation stump, it may be divided into two classifications, (1) the regional gas infection which is localized around the area of the wound, and (2) the fulminating, ascending gas sepsis which is spreading upward beyond the region of the

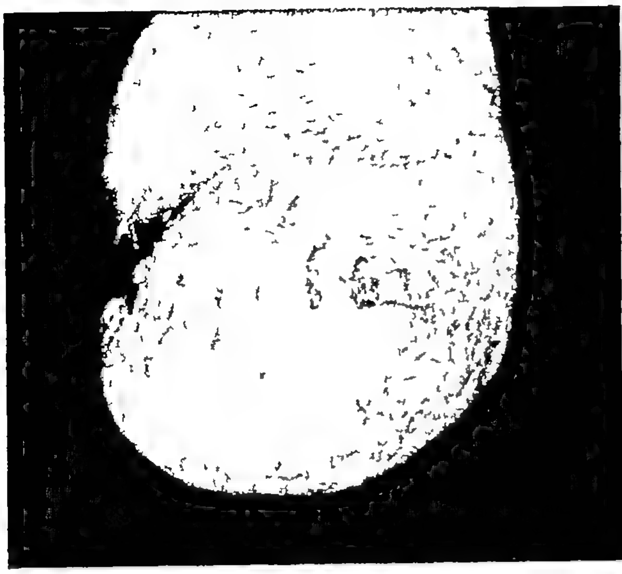

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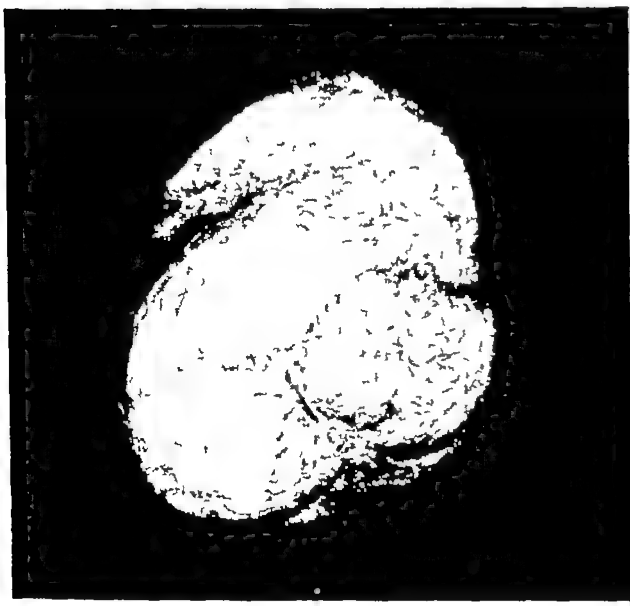
Fig 263—Ulceration caused by sutures placed under tension (Walter Reed General Hospital Neg No 4666 3)

Fig 264—Ulceration of a portion of a skin graft The graft was overlying bone and the ulceration occurred following minimal trauma (Walter Reed General Hospital Neg No 4888 2)



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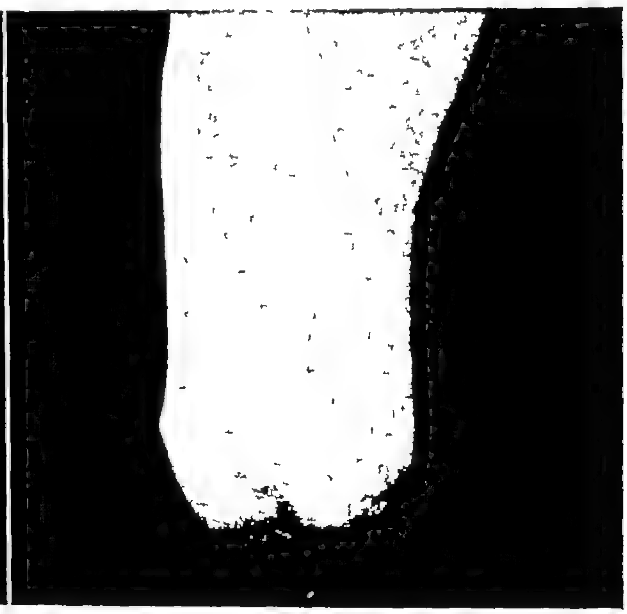

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Fig 265—Ulceration of the end of a below knee stump following imperfect healing of the wound edges after extensive plastic repair Note the scar about the small granulating area (Walter Reed General Hospital Neg No 4727-1)

Fig 266—Healed ulcer at the end of a below knee stump The dimpled area in the center of the old surgical scar denotes the point where the ulcer is fixed to the underlying bone by cicatrix (Walter Reed General Hospital Neg No 4784-2)

wound In the presence of regional gas infection the wound should be opened, muscle groups should be resected to insure that all affected tissue is eliminated, and extensive incision should be carried out to allow thorough drainage, the wound should then be treated as an open amputation In the presence of ascending gas infection, reamputation in accordance with the open amputation technique should be performed at a level which will insure the elimination of all sepsis

The term "**ulceration**" is generally applied to small granulating areas along the surgical scar, which may result from failure of primary healing of the operative wound or from breakdown in an area of unsound cicatrix The failure of the wound to heal with sound, thin, linear scar may be due to any number of causes which are discussed thoroughly in this text in the chapter on Wound Healing Suffice it to say here that this troublesome sequela, ulceration, is likely to occur when the wound edges have not been accurately approximated and there is infolding or inversion of the skin when infection is active within the wound, when a drain has been placed at the very end of the suture line or left in place unduly long, or when the circulation of the tissues at the lips of the wound is impaired This last factor the impairment of circulation, is usually due to tension when the skin has been pulled too tightly over the end of the stump or over a sharp bony prominence when the sutures have been improperly placed, or when there has been excessive postoperative edema, but it may also occur when the surgical scar lies near an old scarred area or when the compression dressing has been applied too tightly No matter what its cause, it usually results in tissue slough about the ulcerated area Ulceration along the suture line will usually heal by broad thick scar, especially if encouraged by the use of warm wet dressings, but such scar will not stand up under use within the prosthesis, for the up-and-down motion of the stump within the socket constantly pulls at the site of the ulcer, which being fixed by cicatrix to the underlying tissues, soon breaks down again and becomes an open wound An ulcer should be treated by elevation, tissue rest, and hot, wet packs until its open surface is clean and the surrounding skin has normal texture When this stage is reached, the ulcer is excised through the normal skin which lies about it and the scar at its base is removed by block excision to the level of normal tissue Since the cicatricial base may often be three-quarters of an inch or more in thickness, it is frequently necessary to perform a plastic rearrangement of the skin or to resect the bone to effect closure of the wound The external appearance of these ulcerated areas is small, and it is a constant temptation to the surgeon to perform a conservative excision, removing only the ulcer and to approximate the skin without removal of the scar tissue base, but such a procedure is valueless, since secondary breakdown with the use of the limb is the general rule Attempts have been made to place pinch or split-thickness grafts over the ulcerated areas, and, although these usually "take," they do not stand up under use

Complications Relative to Length, Shape, Mobility, and Sensation

This group of conditions does not include complications due to improper bandaging of the stump or caused by the use of the prosthesis, it is concerned with the complications relative to length, shape, mobility, and sensation, which arise from errors in judgment or from circumstances beyond the control of the surgeon at operation or immediately thereafter

Complications as to the **length** of the stump may be due to severance at a level not within the areas of election or, as is usually the case with the too

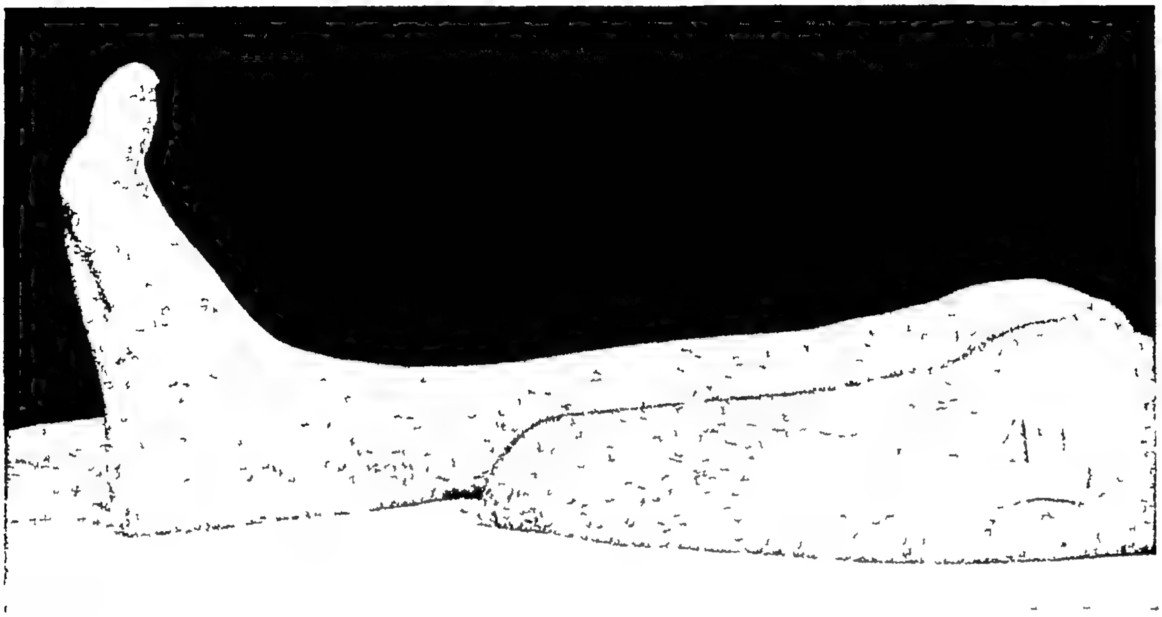

Fig 267—A long below-knee stump When an extremity is severed distal to an area of election, the stump is difficult to fit with a satisfactory prosthesis, and frequently breaks down with use (Walter Reed General Hospital Neg No 4435 1)

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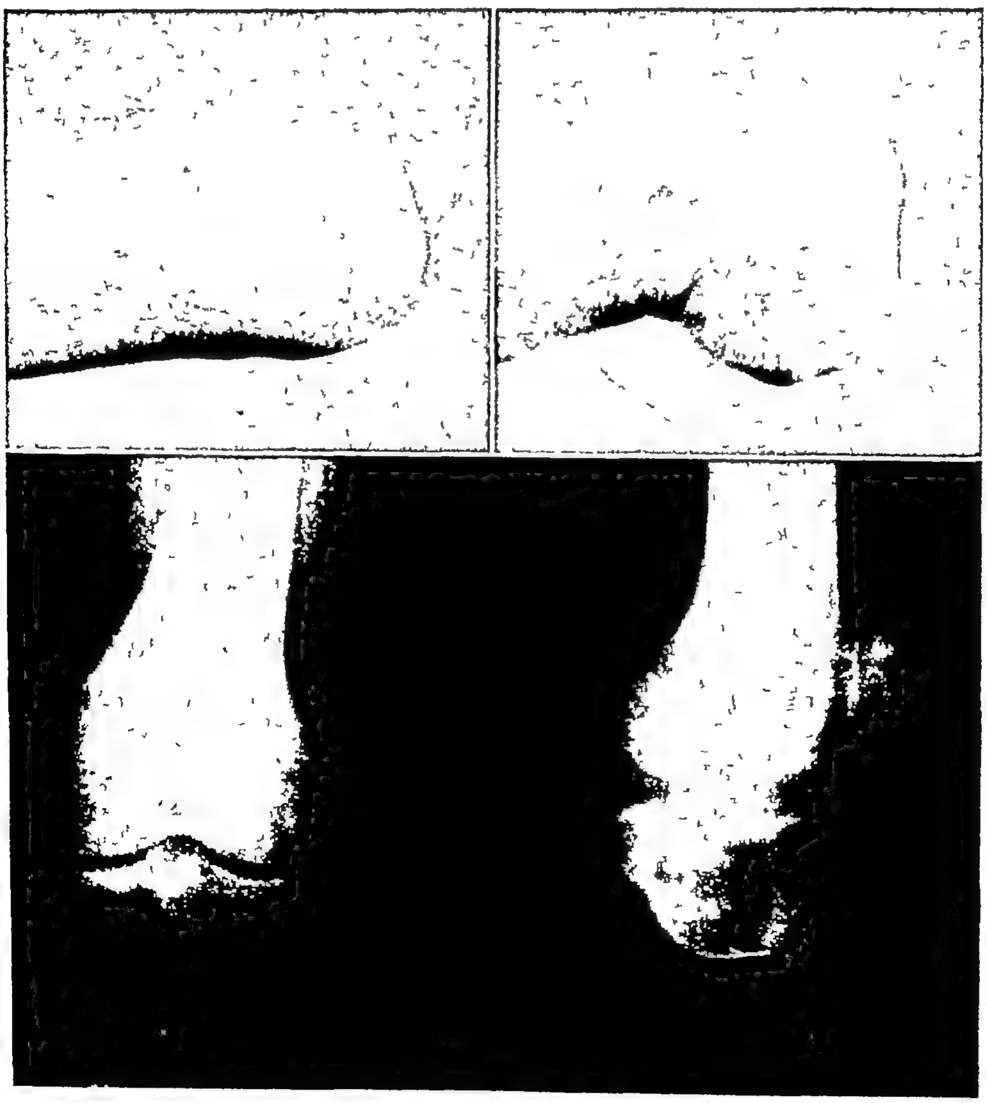

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Figs 268-270—A short below knee stump salvaged for use in a prosthesis through hamstring section (Courtesy of Blair H C, and Morris, H D J Bone & Joint Surg 28 427 1946)

short stump, to tissue slough and loss of length following operation. Normally, amputation should be carried out within an area of election, for there the tissues are best suited to act as protection for the bone and least likely to break down with use, and the resultant stump is of a length which provides the most effective lever arm for activation within the prosthesis, and which can be most readily fitted by a sightly artificial limb. When amputation is performed above or below an area of election, the stump is of questionable value from both the functional and the prosthetic standpoint.

The short stump is ineffectual as an activating force within the prosthesis and is prone to pull up out of the socket during normal use. It is frequently subject to contracture, since it is usually close to a joint where structures are extremely elastic and has not sufficient length to be grasped and maintained in normal position by the artificial limb. Its tissues frequently become avascular and break down because they have been drawn too tightly over the stump end in an effort to maintain all possible length. The overlong stump is sometimes mistakenly thought to be more functional than the ideal because of its additional length, but experience has shown that the extra two or three inches make it no more effective as a lever arm. In addition, it is most unsatisfactory because of the high frequency of breakdown of the suture line due to the avascularity of the tissues involved and the tension placed upon the scar by the excessive up-and-down motion of the artificial limb. Either the overlong or the too short stump presents a difficult fitting problem. Some contend that any amputation stump covered with normal tissues can be fitted if sufficient time, effort, and skill are expended in the construction of the prosthesis. While this is admittedly true in certain highly specialized, noncommercial limb shops, it is not true of the industry at large, and the usual outcome is an ill-fitting and unsightly prosthesis. Nevertheless, an attempt should be made to fit these stumps of atypical length whenever possible. If the short stump has normal tissues, it can often be fitted satisfactorily by the use of special fitting measures; if it is near the elbow or knee joint and such measures do not suffice, tenotomy as described by Blair and Morris may make the adaptation of a prosthesis possible. If the stump cannot be adequately fitted, or if the tissues are abnormal, reamputation at a proximal ideal level is the course to be followed. The long stump in which no vascular changes or tissue breakdown is evidenced should be fitted, but the amputee should be told of the probable unsightliness of the limb and should understand the possibility of future breakdown of the stump. If such fitting is unsatisfactory, or if the tissues of the stump are not normal, the only course is reamputation at a higher site of election.

A word should be said here concerning the short stump in children. Frequently, following amputation, the growth of the stump will be retarded and lag behind that of the normal, opposite extremity. This is on the basis of disuse atrophy similar to that seen in poliomyelitis and some congenital deformities. There is nothing which can be done to incite growth of the stump, and compensation for length should be carried out in the construction of the prosthesis.

As to **shape**, the ideal stump is cylindrical in form and tapers gradually to a smoothly rounded end. Although some modifications of form, necessitated by circumstance, are compatible with functional use, any radical divergence from the smooth, trim contour of the ideal becomes a complication, for it makes the adaptation of a prosthesis difficult or virtually impossible and usually causes the stump to break down with use. Such complications may

be roughly classified into three groups (1) projecting bone, (2) masses of redundant muscle or skin, and (3) malformation occasioned by improper bandaging It is with the first two that we are concerned here

1 **Projecting bone**

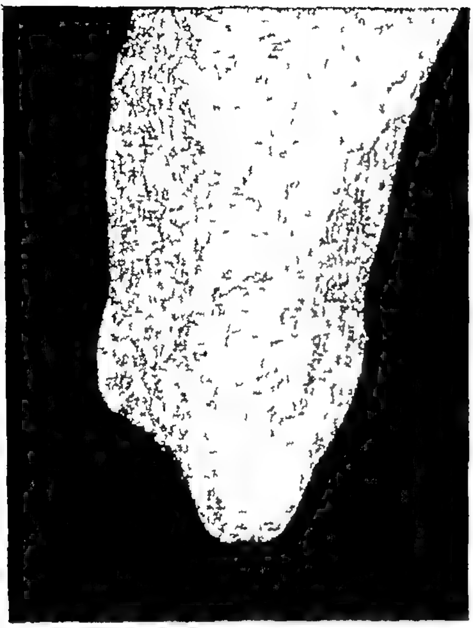
The *"conical stump"* is one in which the end of the bone with its cutaneous covering protrudes in pipelike fashion beyond the muscle mass which would normally protect its sides In adults this is primarily due to the retraction of the muscles because of failure to provide a fixed muscle grouping at the stump end, in children it is usually due to the failure to make allowance at the time of forming the stump for the disproportionate growth of skin and bone, and in the below-knee stump, to take into consideration the fact that the fibula tends to outgrow the tibia It is generally true in children that the rate of growth of the bone exceeds that of the skin following amputation Allowance should be made for this at the time of closure by tailoring the stump with slightly longer muscle and slightly greater redundancy of skin than would be planned for the adult In the below-knee stump such precautions will be valueless if such measures as epiphyseal arrest of the upper fibular epiphysis, synostosis of the distal ends of the fibula and tibia, or high section of the fibula, are not carried out, for there the fibula will push on beyond the tibia, giving the stump an uneven end, and in all likelihood will in time project beyond its circumferential muscle padding "Conical stumps" are exceedingly difficult to fit, for they are subject to blisters, abrasions, and pain on contact with the sides of the socket, but the expert limb fitter can sometimes make them usable Most frequently, however, they undergo vascular changes, become tender, cyanotic, and painful, and eventually require surgical treatment This consists of removing any unsatisfactory skin, resecting the bone to a level where its sides will be protected by muscle, and carrying out the necessary plastic closure

The presence of *bony prominences* and deformities frequently interferes with fitting of the limb and results in a painful stump Fractures in amputation stumps are not infrequent in traumatic cases Here angulation, sharp corners of fracture fragments, and masses of callus may result in bony prominences beneath the skin which are potential sources of pain and pressure sores Should these interfere with function, they should be removed by excision to a point where the bone is smooth and rounded Care should be taken to insure that incisions are short, longitudinal, and placed where subsequent adhesions are least likely to occur Fracture deformities in general should not be subjected to surgical correction before a trial of use with the artificial limb Much can be done to avert the necessity of further surgery if the patient is placed in the hands of a skillful and painstaking limb maker If fitting does not prove satisfactory, however, reconstruction of the fracture or, possibly, reamputation should be carried out

Bony spurs, arising from the cut surface of the bone or adjacent periosteum are usually of little significance as far as fitting is concerned, for they generally conform to the shape of the stump Occasionally one will protrude beneath the skin and removal of it and its investing layer of scar tissue will be required in order that a rounded surface covered with normal skin may be achieved

Frequently, following severe trauma which has resulted in massive loss of soft tissue the bone will rest directly against the skin with no muscle padding If the skin is adequate and normal careful fitting may be the solution to the problem if it is not, or if good fitting is not possible, reamputation is the only alternative

PROJECTING BONE IN THE FINAL AMPUTATION STUMP



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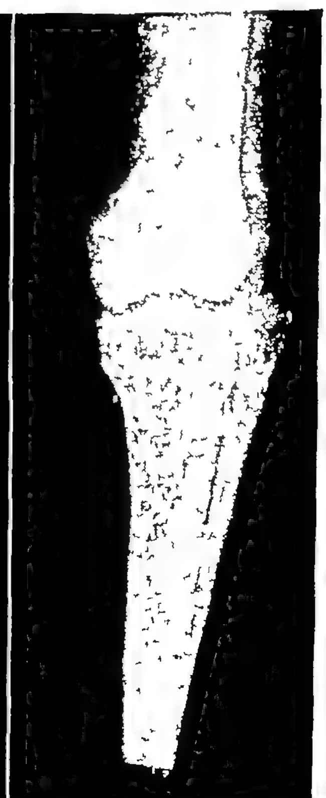

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(For legends see opposite page.)

Fig 271 —The "conical" stump The bone, with its investing skin, protrudes beyond the muscles which would normally protect its sides (Walter Reed General Hospital Neg No 4806 1)

Fig 272 —Bony deformity of a femoral stump following a shell fragment wound Note that nonunion, angulation, and osteomyelitis with sequestra are present, any one of which complications is incompatible with the use of a prosthesis

Fig 273 —Bony deformity of the roof of the shoulder which included loss of the outer end of the clavicle and acromion, and the superior portion of the humeral head, as well as the deltoid muscle Although the patient was improved following plastic repair of the skin over this area, he was still unable to wear a prosthesis because the tender subcutaneous bony eminences would not tolerate the pressure of the harness (Walter Reed General Hospital Neg No 4450 2)

Fig 274 —Bony prominence caused by the splaying of the fibula in wide abduction This patient was not able to wear a prosthesis until the fibula was removed (Walter Reed General Hospital Neg No 4683-A1)

Fig 275 —Bony prominence due to proximal dislocation of the fibula in a vital weight-bearing area The fibula was removed at the time of final surgery (Walter Reed General Hospital Neg No 4698 A1)

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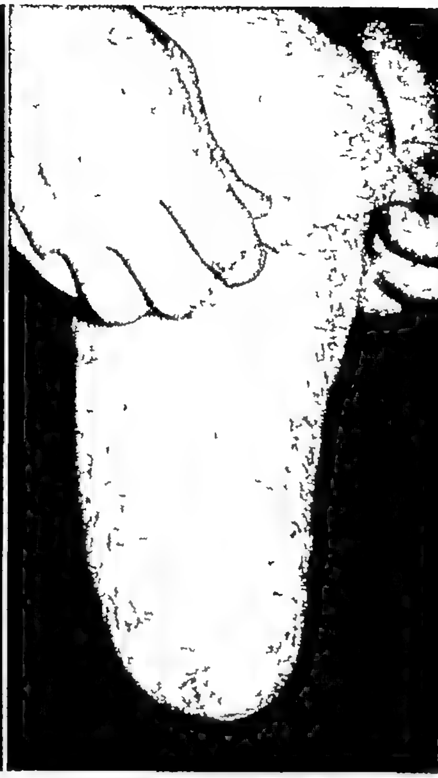

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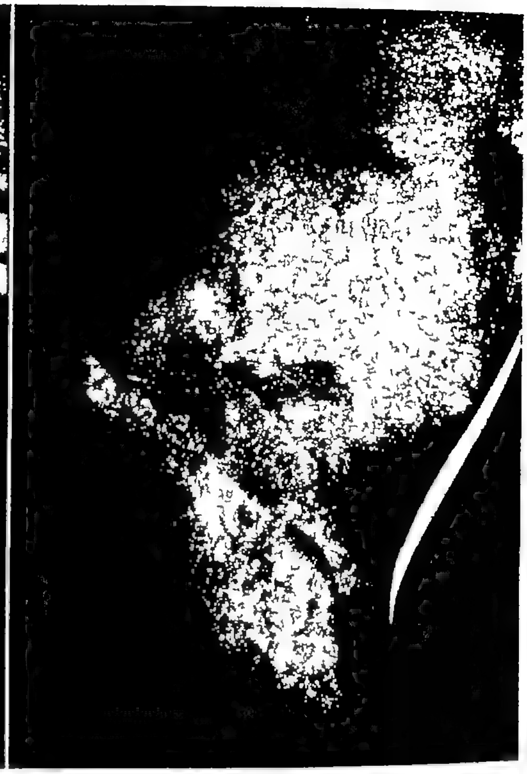

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Fig 276—Redundant skin at the end of the amputation stump In this instance, although the skin hung only a little more than an inch below the end of the tibia, it was a source of discomfort in the prosthesis (Walter Reed General Hospital Neg No 4694 3)
Fig 277—Hypermobile skin (Walter Reed General Hospital Neg No 4729-2)
Fig 278—"Dog ear" (Walter Reed General Hospital Neg No 4871 2)

2 Masses of redundant muscle or skin

The stumps in which there are large masses of *redundant skin and tissue* are most undesirable, for they fit poorly within the prosthesis, becoming bruised, chafed, and irritated by the socket, and are subject to stasis, dependent edema, vascular insufficiency, ulceration, and breakdown Fortunately they are less frequently found now than in the past, when, as was noted in the discussion of muscles in the chapter on the Surgical Care of the Individual Tissues, they were purposely formed in the mistaken belief that muscle formed good padding for the bone end and insured good circulation for the end of the stump When such a stump is found in which no pathological changes have taken place, its bulky form can be fitted by the expert limb fitter, although the possibility of breakdown is ever present When pathological changes are present, surgical treatment should be undertaken The stump should be elevated until all signs of irritation, inflammation, and edema disappear, and plastic revision should then be performed so that the muscles extend only to the level necessary to achieve circumferential padding, and the skin covers the stump end under normal tension

Occasionally, in cases where the skin is extremely *elastic and hypermobile,* there will be a downward migration of the skin past the end of the stump with the use of the artificial limb I have seen one such case which had a perfectly formed stump, repaired with the skin under normal tension, which developed

such redundancy after the use of the limb that two subsequent skin revisions were necessary to eliminate the bulky, newly formed mass over the stump end

"Dog ears" is the colloquialism applied to projecting masses of skin found near the termini of transverse suture lines at the end of the stump, or at either side of a single long flap where it has been folded over the rounded end of the stump In the first instance they are usually the result of failure to form the flaps properly at the time of final surgery, in the second, they are frequently allowed to form purposely, for to prevent them would mean the removal of deep wedges of skin from the sides of the flap, and the subsequent embarrassment of circulation Although they are generally undesirable both from the standpoint of cosmesis and of function within the prosthesis, they seldom warrant surgery unless they are of more than moderate size, for in most cases they will gradually flatten out and become a rounded part of the stump under the influence of simple bandaging For those which do not diminish sufficiently with bandaging, or those which have become swollen, fibrotic, edematous, and undergone circulatory changes, surgical removal is indicated by means of an elliptical incision and approximation of the wound edges

The **loss of joint mobility** is a serious disability in an amputated extremity Not only does the amputation stump appear unnatural, but the power normally transmitted to the limb is restricted, the utility of the stump is definitely limited (especially if the range of motion is in an unfavorable position), and fitting may be either difficult or impossible The factors responsible for impaired motion are first, soft tissue contractures, second, intra-articular damage through injury or disease, and third, bony deformity Of these, the most frequent is contracture of the soft tissues

The *soft tissue contractures* may be of dermatogenic, neurogenic, or myogenic origin, singly or in combination The skin is responsible for contracture when scars placed over the flexor or extensor surfaces of joints become drawn, or when the skin is sewn under tension As for scar as the causative factor in contracture, the principal offender is the longitudinal one (whether as the result of surgery or injury) which lies on the flexor surface of a joint Such a scar will invariably contract and restrict extension Physical therapy and cast wedging are ineffective as treatment, and surgery is required This must be plastic in type, with excision of the cicatrix, and wound closure by the Z-plasty, skin graft or flap method, for if the longitudinal cicatrix is simply excised and resutured, a recurrence of the contracture may be anticipated Scars on the skin overlying the extensor surfaces of the joints are seldom the cause of contracture unless they are large and dense Physical methods should be tried here before surgery is attempted If they are unsuccessful, excision of the scar may be carried out and replacement made by skin graft or flap Occasionally, massive cicatrix involving both skin and deep soft tissue will be encountered, in which resection is impractical because of the size of the defect and the possible involvement of vital structures which might be encountered In this instance corrective osteotomy should be considered, to place the range of motion in the position where it is needed most As for the restriction of joint motion by skin tension, it is usually the result of trying to use an inadequate amount of skin for covering and of suturing it under more than normal tension For example, if a joint has to be flexed to 90 degrees at the time of closure to afford approximation of the wound edges, the skin of the flexor surface will restrict extension after healing has taken place Similarly, if the skin is drawn down very tightly on both the anterior and posterior aspects of the stump, motion will be restricted in both planes Such complications are most commonly seen in fingers but may also be

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(For legends see opposite page.)

Fig 279 —Flexion contracture of the knee joint due to longitudinal scarring, corrected by multiple Z plasty (Walter Reed General Hospital Neg No 4552 4)

Fig 280 —Flexion contracture of the hip secondary to massive deep scarring in the groin, corrected by means of subtrochanteric osteotomy and blade plate fixation (Walter Reed General Hospital Neg No 4387 2)

Figs 281 and 282 —Pre and postoperative views of abduction contracture of the thigh due to massive soft tissue loss in the adductor region (Walter Reed General Hospital Neg No 4487 1 and 4870 1)

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Fig 283 —Flexion deformity of the knee associated with fracture of the distal third of the femur

Fig 284 —Flexion contracture of the knee secondary to intra articular fracture of the distal end of the femur Such a stump is useless if it does not provide an adequate range of painless motion

seen in other joints Treatment consists of reamputation at a higher level or plastic rearrangement of the skin

Contractures of neurogenic origin are seen in central nervous system disease, injury or disease of the peripheral nerves, and in cases where pain of neurogenic origin causes the patient to seek a position of relief Cerebral palsies from Brodmann's area six and Brodmann's area four will cause deformities due to spastic or flaccid paralysis, respectively, tumors, injury, or disease of the spinal cord may cause spastic deformities when the pyramidal tracts are involved, anterior horn cell lesions, notably those due to poliomyelitis, may cause contractures due to the overbalancing of the weakened muscles by their normal antagonists Lesions of the peripheral nerves act in a similar manner Treatment under these circumstances consists of correction of the etiological factor wherever possible, and physical therapy for elimination of contractures and retraining of muscles In cases where painful neuromata are present, and in a few cases of phantom limb, the patient will place his extremity in an abnormal position to gain relief by relaxing deep cicatrix involving the peripheral nerves, if the stump is allowed to remain in such a position over a long period of time, adaptive shortening of the soft tissues takes place and fixes the contracture Since the patient with severe neurogenic pain will not allow the stump to be moved from the position of comfort until pain is relieved, it is apparent that surgical treatment should be undertaken at once to eliminate the irritative lesions It should be followed by physical therapy

Contractures of myogenic origin are due to the loss of one or more muscle groups or to the fixation of the muscle through adhesions When all or a portion of one or more muscle groups is lost, the normal counterbalance of muscle strength is gone and contracture in the direction of the remaining dominant muscle results Such a situation is frequently seen following severe trauma where the muscle has been destroyed by the initial injury, removed during débridement, or excised during the treatment of infection Treatment of the condition consists of physical therapy to reduce the contracture and adaptation to a prosthesis by the construction of a special socket, most contractures of this type will lessen upon use of the stump within the artificial limb Fixation of the muscles which normally motivate the stump may be brought about when the muscle becomes bound down by scar following prolonged sepsis, or when it has adhered to callus about a fracture site In the first instance, contracture can be eliminated by excision of the useless muscle together with the surrounding cicatrix, if such excision does not mean the loss of all motivating power (in which event nothing would be gained by the procedure), if such excision is too extensive to be practical, corrective osteotomy may occasionally be of value, if the contracture cannot be eliminated by either means, an effort should be made to fit the distorted stump by special fitting measures, and if these fail, reamputation should be resorted to Contracture resulting from adherence of the motivating muscle to the callus about a fracture site is most commonly seen in the below-knee stump where the femur has been broken In such a case the adhesion is far less extensive than is that following sepsis, and a larger amount of normal muscle remains If the joint cannot be mobilized following a trial of physical therapy, corrective surgery according to any of the standard techniques should be carried out with a view to mobilizing the remaining normal musculature

Adaptive shortening of the soft tissues in malposition is probably the greatest single cause of stump contracture In most instances it can be avoided by proper care in the preprosthetic period The joint immediately above the amputation stump should be placed in the neutral position during any period of bed

rest (splints should be used if necessary), and in the functional position when bandaging is being carried out. Muscle-strengthening exercises should be performed routinely, with care being taken not to overexercise the dominant muscles in relation to the ones which are weaker by nature or have been weakened through section at the time of surgery, for wherever loss of muscle balance is present, contractures are prone to occur. Soft tissue contractures of this nature should be treated primarily by physical therapy and should be fitted to a prosthesis with special socket (the socket need not be constructed with quite as great a degree of angle within the shell as is represented by the stump itself). Although physical therapy and the use of the artificial limb will usually straighten out most such contractures, the more intractable ones may require placement in a turnbuckle or wedged cast.

Contracture of arthrogenic origin may arise from intraarticular adhesions following in the wake of infection or trauma within the joint, from bony deformity resulting from arthritis or fractures into joints, and from active arthritic processes. The usual medical and orthopaedic treatment of these conditions may be carried out to correct such complications (with the exception of arthroplasty, which generally results in a stump which is inadequate for use within the prosthesis). It is not within the province of this text to go into detail on such procedures. Suffice it to say here that, if surgery is undertaken for correction, scars should never be placed in weight-bearing areas or where they will interfere with function.

Two other complications which impair mobility and preclude the satisfactory use of a prosthesis are ankylosis and unreduced dislocation of a joint with malposition. Ankylosis, whether fibrous or bony, stems from the same conditions as the contractures of arthrogenic origin, it should be treated by standard reconstructive and physical methods, and, if these do not give a satisfactory result, reamputation of the extremity above the affected joint should be carried out. The unreduced dislocation is often mistaken for contracture, it should be treated by the usual orthopaedic procedures.

Increased mobility of the stump is found under two circumstances: the idiopathic jerking stump, and the jerking stump associated with spinal cord injury.

The idiopathic jerking stump is one of the most curious complications. Although it occurs to some extent in nearly every amputation stump, it is more severe in the thigh stump and is generally more marked in high strung, intellectually developed individuals. It is clonic in nature and apparently not on a fatigue basis, but its exact etiology is not known. Some feel that it is due to local irritants such as infection, and others maintain that tender neuromata are its cause, but there is little evidence to substantiate either theory. The patient can often control the jerking motions by grasping the stump for a moment or two, by supporting it firmly, or by sheer will power, but there is little in the way of treatment which is of value. The use of the prosthesis usually quiets down the jerking motion to some extent.

The spasmodic jerking of the stump found in paraplegic amputees is secondary to injury within the spinal cord. Its treatment is dependent upon the neurologic approach and is not within the scope of this text. It is mentioned here as a differential point which must not be confused with idiopathic jerking.

When **sensation** is not present in an amputation stump, the skin is easily abrased or contused without the patient's knowledge. When the artificial limb is worn, the pressure over bony prominences of the asensitive stump often leads to the formation of decubitus and frequently open ulceration. In areas

Decubitus ulcer in anesthetic skin overlying the ischial tuberosity in a case of hip disarticulation Surgical treatment of gas infection here resulted in severance of the cutaneous nerves and multiple scars

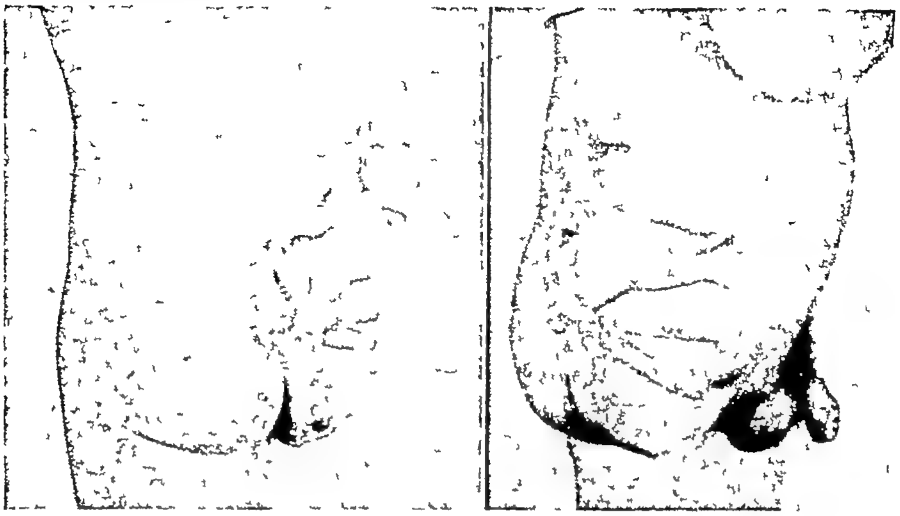

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Fig 285 —Posterior view (Walter Reed General Hospital Neg No 4298 3)
Fig 286 —Lateral view (Walter Reed General Hospital Neg No 4298 1)

Fig 287 —Posterior view following plastic repair In stage operations the skin was migrated downward a distance of five inches to supply the ischial tuberosity with skin covering possessing normal sensation (Walter Reed General Hospital Neg No 4846 1)

where no prosthesis is worn, such as in the hands, the skin is unduly susceptible to chemical and thermal injury with secondary tissue breakdown. Treatment consists of reamputation at a higher level where sensation is normal, or, in the cases of amputation about the hip or shoulder, plastic procedures to place flaps carrying sensation in crucial areas where pressure is usually borne.

Complications Due to Pathological Changes of the Tissues Within the Stump

Vascular Disturbances and Skin Affections

In studying the vascular disturbances and skin affections of the stump, it becomes apparent that there are two general etiological factors—the conditions which form a background for pathological changes in the tissues, and the use of the prosthesis. In some instances, the conditions which give rise to pathological changes are in themselves sufficient to result in complications; in many, these conditions might be tolerated without complications ever arising if it were not for the aggravation caused by the use of the artificial limb; in yet others, the vascular disturbances and skin affections are due directly to the wearing of the prosthesis alone, with no other causative factor. For the sake of clarity here, the circulatory and dermatological complications which stem solely from the use of the limb will be deferred to a later portion of this chapter, and only those with a background of pathological conditions within the stump will be discussed in the pages immediately following.

Circulatory disturbances of an amputation stump may be secondary to extensive scarring, may be due to disease of the blood vessels, or may follow vascular trauma. They are most destructive, for they impair the immediate usefulness of the stump and, in time, if uncorrected, will result in breakdown, tissue slough, and eventual loss of length.

Excessive scarring within the stump is one of the most common causes of circulatory disturbances. It usually follows in the wake of severe trauma or infection and results in chronic congestion of the stump, which is manifest early by pain, a pinkish appearance, and increased warmth. Later the stump becomes cold, thickened, and dark red to purplish in color. When this stage is reached the stump is particularly liable to abrasions and ulceration. If the condition is recognized early, the stump can usually be preserved at the original level of amputation by conservative treatment: a period of prolonged elevation, abstinence from weight-bearing, Buerger's exercises, and the use of an elastic stocking when the extremity is in the dependent position, and, when tissues and circulation again appear normal, very gradual re-adaptation of the prosthesis. If the condition has not been checked in the early stages, and fixed, irreversible, pathological changes are present, or if the conservative measures noted above have not restored the usefulness of the stump, the scar should be excised and plastic closure re-effected. If excision of the scar is impractical because of its diffuse nature or its location, reamputation should be carried out.

Peripheral vascular disease is most common in the lower extremities below the level of the knee. When it is present in the amputation stump the degeneration of the blood vessels, which is characteristic of it, causes circulatory deficiency within the deeper tissues, and the stump lacks resistance to minimal trauma or infection and cannot tolerate even the slightest constriction. It is evident that such a stump will be constantly subject to abrasions and will be seriously affected by bruises and the small injuries which may occur in the course of normal use; it is equally apparent that it will be extremely liable to circulatory breakdown upon use within the artificial limb. This is particularly true since it is the below-knee stump which is usually affected by the disease for

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Fig 288—Breakdown and infection of the foot due to deficient circulation in a case of thromboangiitis obliterans (Walter Reed General Hospital Neg No 2638 1)

Fig 289—Chronic swelling of a thigh stump due to lack of collateral circulation following an extensive lacerating wound of the groin involving the femoral vessels Similar swelling may result from the surgical ligation of the femoral vessels for the control of bleeding

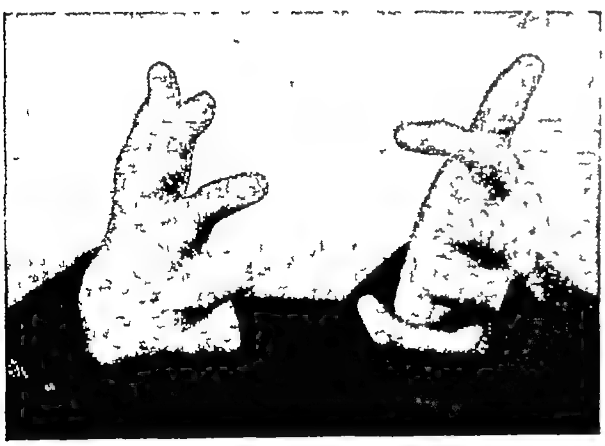

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Fig 290—Frostbitten hands with amputations of the fingers Note the atrophy of the fingers, the tense, glistening skin, the ankylosed joints, and the healing of the end of the stumps by scar Such scarred areas are subject to breakdown on minimal trauma (Tonopah Army Air Field 1138A)

Fig 291—Frostbitten foot illustrating breakdown and ulceration in the region of the first metatarsal bone, following attempted plastic repair by means of skin flaps (Walter Reed General Hospital Neg No 4751-1)

the weight-bearing prostheses for the lower extremity require snug fitting and the constriction by the socket would cause further disruption of the already abnormal circulatory flow

Peripheral vascular disease is sometimes found in the foot when minor amputation has been performed in its presence to remove a deformed or infected toe The rules governing such a procedure are exceedingly stringent, as was noted previously Sometimes vascular changes in the resultant stump occur because these rules have been violated, sometimes because circumstances unforeseen or beyond the control of the surgeon have developed and the disease has progressed In either event the circulatory deficiency is highly incompatible with function, for any minimal injury or infection will result in secondary breakdown When breakdown does occur, the usual therapeutic measures indicated for this disease should be administered, and if sound healing will not then take place, amputation above the knee should be performed

Peripheral vascular disease is more frequently found in the below-knee stump in those cases where amputation was performed originally because of the presence of the disease but was not carried out at a high enough level to eliminate it This failure to perform sufficiently high section of the extremity does not often occur when the indication for amputation is on the basis of arteriosclerosis, for there the lack of blood supply is self-evident and any incision would readily demonstrate nonviable muscle and other soft tissues It does occur all too frequently, however, in the below-knee stump when amputation is indicated by the presence of Buerger's disease, for there the collateral circulation at the time of surgery is excellent and would seem to indicate abundant blood supply at the surgical site, careful observation, however, would reveal that the principal vessels are occluded, or nearly so, and microscopic investigation would usually show that the smaller vessels are involved When amputation is carried out below the knee under these conditions, primary healing may take place and the stump may appear to be excellent, but the repeated experience has been that circulatory breakdown will occur in such cases within a year or two, and reamputation will have to be performed above the knee Despite the recognition of this fact, there are two circumstances under which below-knee amputation in the presence of peripheral vascular disease is indicated first, in the bilateral amputee who already has one above-knee amputation and may be tided through several years of comfortable walking by having one below-knee stump, and second, in the patient who has a potentially suicidal maladjustment to amputation (Here the below-knee amputation is considered a palliative psychiatric measure to allow the patient to adjust to his new situation If such a stump is present and the disease is negating its usefulness, amputation above the knee is almost routinely required

When the *major blood vessels to an extremity have been severed* by a penetrating or lacerating wound, and amputation has resulted, the venous and arterial flow is diverted into the collateral circulation In many instances, circulatory readjustment is a very slow process, requiring months or years, for the abundance of scar tissue throughout the region of the vascular bed makes the establishment of new blood channels difficult This congestion may result in swelling which will preclude the use of the limb, or the application of the prosthesis may aggravate the situation and, by so doing, be the cause of swelling so that its use will have to be restricted The use of the pressure-suction apparatus and operations of the Kondoleon type in an effort to relieve the congestion are seldom attended by any remarkable degree of success The greatest improvement is usually achieved by the use of an elastic stump sock which may

be worn with the prosthesis, by ischial weight-bearing in the below-knee type of amputation, and by whirlpool and other physical methods

Another, rather unusual, complication is *traumatic aneurism* This usually follows penetrating wounds involving the major blood vessels and may be of any of the classic types described in surgical manuals The treatment is surgical, and technical description of the operation is not within the scope of this text, but a word of warning should be given regarding the placement of incisions they should always avoid weight-bearing surfaces utilized by the prosthesis if it is possible to do so, and they should never be longitudinal over the flexor aspects of joints because of the danger of secondary flexion contracture of the skin In the latter instance the conventional S-shaped incision is usually the procedure of choice to give the necessary exposure

Frostbite is an extremely destructive form of trauma which causes vascular changes and local tissue necrosis in all of the structures which it touches In contrast to peripheral vascular disease, which brings about pathological changes in the blood vessels within the deeper tissues of the extremity, frostbite brings more severe degenerative changes to those lying in the skin and subcutaneous tissues, and its effects become progressively less grave as the deeper structures are approached It differs from peripheral vascular disease also in that it is common in both the hands and the feet The differences between the two are due to the fact that frostbite is an outside agent which affects the parts of the body least protected from exposure and possessed of the least rich blood supply The stump which results from amputation for frostbite is commonly subject to two complications

(1) Pain which has its etiology in perineural fibrosis and ischemia, and
(2) breakdown and ulceration of the skin under minimal use and trauma because of the marginal blood supply

No treatment has been found particularly efficacious in combating pain because the fibrosis responsible for it is fixed and irreversible once it has become established Most cases improve somewhat with time and use As for ulceration of the stump, the area should be treated surgically when the granulating surface has been cleansed by saline dressings (Although in some cases healing may take place by thin avascular scar following the use of ointments and moist applications, this is usually only temporary, and the scar will in most instances break down and require secondary operation) Surgical treatment consists of removal of the ulcerated area and plastic closure by skin flaps which contain all layers of soft tissue down to bone (these layers are not separated) Bone, scar tissue, avascular fascia, and tendon should be trimmed away to a point where the skin flaps will fall together easily without tension It is important in performing such a procedure on this type of stump to bear in mind that

(1) Mobilization of the skin at the level of the deep fascia usually results in breakdown of the wound with skin slough since this skin has very marginal blood supply, withstands even gentle manipulation poorly, and has little elasticity due to extensive intracutaneous fibrosis, and
(2) free skin grafts are usually unsatisfactory and tube and pedicle flaps heal only with difficulty because of the poor circulation of the area to be grafted

Affections of the skin form a group of complications of the healed stump, which, although trifling in appearance, become magnified in importance when

the patient is "grounded" and unable to use the artificial limb. This is readily understandable when it is seen that the slight pressure exerted by the snug fit of the socket may cause unbearable pain and irritation if the stump is affected by even so trifling an affection as a pimple. Since the skin of the amputation stump was never intended for weight-bearing, as is necessary in the lower extremity, or for encasement in the socket of a limb as is the case in the upper extremity, its adaptation to these functions requires constant attention and careful administration of both prophylactic and therapeutic measures if convalescence is to be minimized and rehabilitation hastened. The most effective means of forestalling any dermatological complications are dealt with in detail in the section on the Care of the Individual Tissues and, further, in the discussion of stump hygiene. Let it be said here that the skin to be used for covering for the stump should be normal and healthy at the time of operation, that the techniques for handling that tissue should be faithfully observed, that cleanliness of the stump should be absolutely assured at all times, that therapeutic measures for the improvement of skin tone should be carried out, and that care should be taken in the manner of wearing the stump sock, and stump sock hygiene should be meticulous always.

The most common skin disorder seen in amputation stumps is *folliculitis*. This condition is staphylococcic in origin, is aggravated by the use of the artificial limb, and is most common in dark-complexioned, hairy individuals with oily skin. Although it appears occasionally in clean stumps with soft, atrophic poorly vascularized skin, in which case it is usually precipitated by the application of oils and greases, it most commonly follows in the wake of poor stump and stump-sock hygiene. Cleanliness, then, is the principal prophylactic measure. In those with a tendency to recurrent folliculitis, careful daily bathing of the stump with alcohol is very valuable. I have also found that the reduction of the bacterial flora of the skin by the regular use of a soap containing 2 per cent G-11 compound produced a significant decrease in recurrence in these cases. Once hair follicle infection has occurred, the milder cases can be treated by thorough and repeated cleansing of the stump with soap and water followed by alcohol, and abstinence from use of the limb. More severe cases can be treated by hot packs of normal saline three or four times a day. Mild antiseptic soaks of boric acid, Burow's, or potassium permanganate solutions may be used as alternates. For resistant or recurrent cases, antistaphylococcic serum may be of value, especially when the organism from which the serum is prepared is obtained from the patient.

Furunculosis is also staphylococcic in origin. It may result from extension of folliculitis or from localized pressure, or it may be a manifestation of generalized furunculosis. Mild cases are treated locally in essentially the same way as mild cases of folliculitis. In severe cases, continuous hot packs, antistaphylococcic serums, and antibiotics may be used.

Uninfected *sebaceous cysts,* if small, are of no moment, if large, they may become a source of discomfort and should be excised. Infected sebaceous cysts, if small and localized, should be treated in the same manner as folliculitis or furunculosis, if large or in groups, they may seriously affect the function of the stump within the prosthesis and must often be removed. The most common example of extensive sebaceous adenitis is in the adductor region of the thigh stump. There it is caused when the stump is forced into a too tight socket and the skin is pushed upward over the adductor rim of the prosthesis to form a "roll of fat," which in time becomes hard, edematous, and chafed and eventu-

ally becomes infected. Prophylactic treatment consists of removal of the artificial limb for a period of several weeks and refitting of the limb in such a manner that the roll of skin will not re-form. If the roll has become fixed by diffuse fibrous tissue or has become severely infected, it cannot be corrected by such a simple measure, but the affected area, once the sepsis is controlled and the process is quiescent, must be excised, care being taken to place the scar as high as possible so that it will not be subject to pressure from the socket.

Milaria or heat rash occasionally appears on the stump and is treated by removal of the artificial limb and, if mild, the application of alcohol; if more severe, the application of hot soaks several times a day.

Of all dermatological affections, *eczema* is by far the most troublesome and resistant to treatment. It appears about the distal two to three inches of the stump, which gradually becomes swollen, dull red in color, and infiltrated with fibrous tissue, and often weeps. The etiology of this condition is not known, but it is probably on the basis of impaired circulation and infection, for it is similar in appearance to the eczematoid infection found about the draining sinuses in chronic osteomyelitis. Treatment is directed toward the eradication of any local focus of infection. Bed rest and elevation of the affected extremity are carried out to eliminate edema and afford tissue rest, and a bland ointment such as zinc oxide is applied to the skin in the affected area. Physical therapy is of little help in this condition, for whirlpool and massage tend to aggravate it, while heat from any of the various modalities and ultraviolet light lend little toward improvement. In the below-knee amputation, which is the most frequently affected, I have used an ischial-bearing type of prosthesis in which the socket has been removed and a loose, soft lining substituted, and have allowed the patient to be up and walking with the stump bandaged with an elastic bandage to prevent further dependent edema. Most cases have responded very well to this treatment and, usually, after three to four months, have been fitted with the conventional socket. I feel that the success of this method depends entirely upon the improvement of circulation of the distal end of the stump through use of the extremity. If these measures fail, there is no alternative other than excision of the affected area to a point where normal skin is present.

Intertrigo is an area of maceration occurring between two opposing folds of skin. Skin folds may develop as the result of improper surgery, improper bandaging of the stump, or through shrinkage of the stump through atrophy or general weight loss. As intertrigo develops, an area of reddening appears on the skin at the point where two folds rub against one another. This is followed by edema, weeping, and fibrous tissue infiltration. As this progresses, fungus infection may develop in the moist boggy skin. Treatment in the early stages consist of thorough stump hygiene, and the use of alcohol, dusting powders, and fungicidal solutions. If the condition has passed into the stage of weeping and fibrous tissue infiltration, the skin folds should be strapped or bandaged apart, the stump should be elevated and alternating application of moist packs and exposure to the air should be carried out. If the intertrigo fails to heal or recurs repeatedly after the use of the limb, surgical excision of the area with plastic reapproximation of the skin is indicated.

Dermatitis medicamentosa is frequently seen in amputation stumps which have been subjected to the use of strong soaps and antiseptic drugs. Treatment consists of discontinuing the use of these substances.

Dermatitis of the stump may not be a local condition but merely a part of a general body involvement. This, of course, requires the treatment of the

specific disease process In like manner, allergy or drug sensitivity may also be manifest as a skin lesion There, too, treatment of the primary condition is indicated, with removal of the offending protein or drug The patient must refrain from the use of the limb in these instances until the process has cleared

Pain

Pain in an amputation stump may arise from three sources **infection, irritation of the peripheral nerves,** and the **phantom limb** state In differentiating between these it is necessary to evaluate the type of pain, that is, whether it is pain which is present when the limb is at rest, whether it is pain associated with pressure (tenderness) or movement of the stump, or whether it is pain, with or without tenderness in the stump, associated with phantom limb phenomenon In addition, it is necessary to make a careful clinical laboratory, and x-ray study of the patient before final decisions are reached

Infection of soft tissue or bone is one of the most common causes of pain The distinctive features of this type of pain are that it is present at rest is associated with tenderness and aggravated by the use of the artificial limb, and is frequently subclinical In this last respect, pain secondary to infection may be spontaneous in origin, may be associated with minimal trauma, or may remain severe beyond the anticipated time following major trauma If the infection is low grade and deep-seated, general manifestations of sepsis will not be present and the local picture will not be diagnostic in the early stages The classical signs of inflammation, however, will make their appearance as the process develops Whenever pain is present with the limb at rest, and no other cause is clinically evident, the diagnosis of infection should be made Before treatment is undertaken, x-rays should be taken to demonstrate the involvement of the bone and the presence of sequestra Once instituted, treatment consists of chemotherapy, localization by hot packs, and appropriate surgery where indicated The bone within the stump is not disturbed unless there is definite x-ray evidence of a bony focus or sequestrum, or there is evidence of osseous involvement at the time of soft tissue surgery When surgical drainage is undertaken, the incision should be long enough to afford efficient drainage (lancing of the abscess is not sufficient since it inevitably leads to chronicity and sinus formation) and should not be carried over bone which lies immediately beneath the skin unless there is an absolute surgical indication to do so, since convalescence is definitely delayed and later plastic procedures are more difficult Incisions should always be placed where they will do the least harm to the future function of the stump, preferably they will follow the old surgical scar, but if extensions beyond this point are necessary, they should be longitudinal in type and be placed on the medial or lateral surface of the stump

The **pain of peripheral nerve origin** may be present when the nerves are exposed following open amputation, when they form inherently painful neuromata, and when they are caught in scar tissue either at or above the suture line In these instances pain is not associated with phantom limb and is not present when the stump is at rest, but it is present upon pressure or upon manipulation of the stump

In *open amputation,* the nerves should be transected so that their cut ends will fall immediately above the muscle edge where they will be somewhat protected Sometimes, through an error in technique, however, the ends will be exposed so that they are painfully subject to manipulation during change of

dressings, and to pressure from the dressings, from the weight of the bedclothes, etc This pain is usually minimized by the use of petrolatum jelly gauze for the first few changes in dressings and gradually subsides as granulation tissue grows over and protects these delicate points As traction pulls the skin down over the open end of the wound, further protection is afforded

The *neuroma* which forms at the end of every sectioned nerve is the normal response to healing and is an attempt on the part of nature to regenerate the nerve The axis cylinders proliferate and push downward, then, finding no channel along which they can pass, become enmeshed in scar to form a ball of nerve and cicatricial tissue, if sensory fibers are contained in the nerve trunk, they will be capable of transmitting painful stimuli upward to the brain in spite of the fact that they have lost their specialized nerve endings A neuroma may develop enough intraneural scar and a large enough terminal bulb that pressure upon overlying tissues will evoke painful stimuli, or it may be fixed within extraneural scar tissue and incite pain when the tissues move or are subject to pressure In the first instance, the painful neuroma is usually due to rough handling of the nerve or the use of sclerosing solutions at the time of surgery Such a neuroma is generally tolerated fairly well, since it is painful only on pressure, which can usually be relieved by proper fitting of the limb If relief cannot be afforded, however, the neuroma should be removed by surgical means In the second situation, the extraneural scar may be either local or diffuse, and the fact that the neuroma is in it is usually due to the failure at the time of surgery to make sure that the nerve end has retracted well above the surgical wound and the area of traumatized tissue Pain which is caused by the implantation of a neuroma in extraneural scar occurs on motion as well as pressure and is highly incompatible with the use of the artificial limb, once it has been differentiated from pain of the hyperesthetic or phantom limb type, surgical treatment should be undertaken to remove its source I am not in agreement with those who refrain from surgery under these circumstances on the basis that the neuroma will reform and will again become painful, for experience has shown that the new neuroma which will form need not be painful (1) if a diagnostic Novocain test is first given to determine whether or not pain can be relieved through interruption of nerve impulses, and to identify the exact extent and location of the painful area, and (2) if surgery is of the proper type and extent, i e, if the excision of the neuroma is carried out at a level where the nerve and surrounding soft tissues are normal and free from scar, and if handling is gentle throughout

The surgical procedures for the relief of neuroma pain may be divided into

(1) *Simple excision of a neuroma made painful by intraneural scar*

The painful neuroma is excised and the newly sectioned nerve end is allowed to retract above any anticipated scar area

(2) *Excision of neuroma together with local extraneural scar bed*

The excision of the neuroma should be done through the old surgical scar wherever this is possible The dissection frees the neuroma from its bed and removes all surrounding scar The nerve is then dissected upward to a point where the tissues are normal, where it is sectioned by a sharp knife or a razor blade (Section should be at least one to one and one-half inches above the bone end)

It is fairly common for the neuroma of a small cutaneous nerve to be fixed at the suture line during the healing of the surgical wound

There it appears as a tiny white point in the scar, which is painful even on light touch or pressure, or upon movement of the skin about it. The neuroma and the local area of scar are excised and the small cutaneous filament is drawn down gently, sectioned, and allowed to retract to a higher level.

(3) *Block excision of a neuroma, or several small neuromata, and the diffuse extraneural scar*

In instances where there is massive scarring, diffuse throughout the tissues, major and minor nerves are often bound within a block of scar. Here it may be impossible to dissect out each nerve as a separate entity, and block dissection of the entire scarred subcutaneous area must be carried out to ensure that each tiny branch is completely free from scar. In those cases where block dissection would mean the loss of adequate normal skin for wound closure, the procedure described below should be used.

(4) *Interruption of the nerve at a point proximal to the extraneural scar*

The local approach to the neuroma may be impractical for a number of reasons: resection might mean such extensive loss of tissue that the future utility of the stump would be endangered; the neuroma might be so deeply imbedded that it would require an unreasonable amount of surgical exploration to find it; for economic or psychological reasons, it might be undesirable to remove the patient from his limb for the length of time required for convalescence. Under such circumstances, the nerves supplying the painful area in the stump may be interrupted at a proximal level and an inch or so resected. When this is done, the incision should always be placed above the level of the socket of the artificial limb to avoid impairing the integument of the stump. Thus, in the below-knee stump the nerves are resected in the popliteal space; in the above-knee stump the sciatic may be approached through a gluteal incision while the femoral nerve may be resected intrapelvically; in the forearm stump the median, ulnar, and radial nerves may be resected at the supracondylar level, and in the above-elbow stump the axillary approach will afford access to the major nerves.

In all four measures, the following points should be observed: no sclerosing solutions should be injected into the nerves, for these form the basis for intraneural scarring; hemostasis should be carefully secured to prevent hematoma, which would encourage future scar formation; and fatty or areolar tissue, if available, should be used to cover the nerve bed, provided this can be done without disturbing the blood supply.

Pain does not always occur in conjunction with the **phantom limb** phenomenon. Almost every amputee will have periods when the lost portion of the extremity is actually mentally present below the site of amputation. This is most likely to occur immediately following operation and to lessen as time elapses. Many weird and bizarre pictures have been described by amputees; most common are the tightly clenched phantom fist with the nails digging into the hand, and the phantom hand arising directly from the above-elbow stump. (This failure to visualize a segment of the limb recurs in many testimonials.) If the phantom limb is not painful, and if the patient is aware that the phenomenon is not unusual, he will not in most instances find it bothersome. *Painful*

phantom limb, however, is another matter, and is one of the most troublesome of all amputation sequelae. Once it has become established, it may become so excruciating that sleep is impossible and normal daily activities cannot be carried out. Morphine and other hypnotics are usually of no avail, and addicts are frequently found among those who have taken refuge in them. The exact mechanism of its etiology is not known. Numerous theories have been brought forward, none of which seem to satisfy all conditions and results of treatment. One school believes that the pain is peripheral in origin and arises from cicatricial compression of nerve fibers, irritation of cutaneous nerves, or an ascending neuritis of the peripheral nerves extending to the spinal cord. The second group believes that the pain is central in origin and psychic in nature, and takes the form of an obsession neurosis. While there is unquestionably a large psychic element in this condition, I cannot help but believe that there is a peripheral source of excitation which is, at the onset of the condition, the motivating source of pain. This exciting force may, of course, be later sublimated by the psychic overlay. In favor of the theory of peripheral origin is the occasional success of operations on the stump, the frequent success of sympathetic block in alleviating the pain, and the fact that, with improvement in surgical techniques to the point where soft tissue infection is limited to the surface in open amputation, phantom limb occurs less often than formerly. In favor of the central origin is the frequent failure of almost every peripheral surgical procedure, and the fact that the parts of the limb which have the greatest representation in the cerebral cortex are the most prominent.

> "There are no peripheral end organs to account for the sensory impressions of posture, touch, movement and the like, the patient usually feels most vividly the parts of the limb that have the greatest representation in the cortex (i.e., the hand, index finger, etc.), the fixed posture of the phantom is commonly reported to be that in which the injured limb was last seen by the patient, and, finally, the evidences of nervous and emotional instability which may be evident by the time the patient comes under observation in his quest for medical assistance, are said to indicate a temperament that favors the development of an obsession neurosis." (W. K. Livingston.)

The treatment of phantom limb pain has been discouraging indeed. Although, occasionally, resection of a peripheral neuroma will afford relief, the interruption of the sympathetic pathways by procaine injections and resection of the sympathetic chain have probably given the greatest percentage of improvement. In many cases one or more sympathetic blocks will apparently interrupt the neurogenic pathways and result in a sublimation of the painful impulses. If this is permanent, and the patient can tolerate his pain, that is all that is necessary; if not, surgical eradication of the sympathetic chain is indicated. In instances not relieved by the sympathetic nervous system approach, neurosurgical procedures directed toward severance of the pain pathways have been tried but have not been attended with any remarkable degree of success. Numbered amongst these procedures are posterior root section, cordotomy, medullary tractotomy, and ablation of the portion of the sensory cortex in the brain corresponding to the painful area in the limb. With regard to this last, it has not undergone extensive trial and is reserved for severe and potentially suicidal cases.

Hyperesthesia of the stump, not associated with phantom limb, does not have a known etiology, although the pain has been thought to be of vasomotor, peripheral irritative, or central origin. Local treatment of the stump does not

relieve the pain, and reamputation is attended by hyperesthesia at a higher level Sympathetic chain interruption should be tried for it gives occasional favorable results In view of the possible central origin, local treatment is stopped, so as not to draw the patient's attention to his condition Little else can be offered the patient except to encourage him to await the subsidence of pain with time

In most lower extremity amputees there may be painful sensations in the stump and the phantom limb of the painless type during the acts of urination, defecation, and ejaculation Patients seldom voluntarily tell the surgeon about this type of discomfort, but its existence can usually be verified by questioning It is most common in thigh amputations, especially those about the hip Pain is greatest in the immediate postoperative period and gradually diminishes, seldom lasting over six months Its cause is probably increased intra-abdominal pressure on the vascular bed, and its importance lies chiefly in relieving the patient's mind of the fact that something has gone amiss, and in assuring him that this is a usual but temporary, state of affairs

Complications Due to Improper Bandaging

In the immediate postoperative period, bandaging is used to minimize hemorrhage through compression, to prevent undue edema, and to aid in immobilizing the tissues Later, it is used to promote shrinkage and to mold the stump to a point where it can be fitted with an artificial limb Bandaging must be done carefully, for haphazard or erroneous application may result in complications so serious in their extent that they affect the future utility of the stump (For more detailed discussion and illustrations, see chapter on Physical Medicine)

Pressure sores with skin slough and ulceration are to be found where the bandage has been wrapped too tightly over bony prominences This is done most frequently at the time of operation, when the surgeon, in an effort to control postoperative hemorrhage, applies the elastic bandage under great tension To avoid pressure sores, the bandage should be placed under moderate, instead of strong, tension, and bony prominences should always be padded in such a manner that the pressure over them is no greater than that upon surrounding skin (Special care should be taken in this respect when bandaging thin individuals) If the patient complains of burning pain over a bony prominence, the bandage should always be removed for inspection of the stump, following the postoperative period, when the patient has been taught to apply his own bandage for shrinkage, there is little danger of pressure sores developing, for he will remove the bandage himself if pain is present When a pressure area has reached the stage of skin slough and ulceration, it must be treated surgically in accordance with the technique used in the final repair of the open amputation stump

Infolding of the skin usually takes the form of a deep crease at right angles to the suture line In time, the base of the crease will become scarred and fixed to underlying soft tissue and bone, and the adjacent skin will become boggy and edematous It results when a circumferential turn just above the end of the stump is drawn more tightly than those at the distal end of the stump, and it is more liable to occur when the skin is loose because of weight loss, shrinkage, or the manner of tailoring the stump at the time of operation It is found most frequently in the below-knee stump (particularly when shrinkage is rapid) and the long thigh stump In the latter instance the thin, pliable, elastic skin in the popliteal region tends to fall between the hamstring muscles even with careful

wrapping, because of the lack of muscular support at this point; this tendency may be avoided by drawing the medial and lateral hamstring muscles together and fixing them with several stitches at the time of surgery. Early recognition of infolding is essential, for in the first stages it can be corrected by the cessation of bandaging or by the application of the bandage in long oblique, rather than circumferential, turns, in such a manner as to pull the bulging tissues to the sides of the stump; in the more advanced stage the tissues may become so bound by the scar at the base of the crease that surgical excision of the cicatrix and secondary revision of the stump may be required.

"Choking" occurs when the bandage is wrapped more tightly at the proximal than at the distal end of the stump and the pressure is great enough to compress the venous channels but not enough to block the arterial inflow. The tissues distal to the constriction become boggy and edematous. This condition can be rectified by applying the bandage so that pressure is distributed equally throughout the stump and constriction is not great enough to occlude venous return.

Abnormally shaped stumps are not uncommon, and are usually the result of the pressure of the bandage being unequally distributed throughout the circumference of the stump. If the bandage is wrapped more tightly about the proximal portion of the stump than about its distal end (the same erroneous method which results in "choking"), the stump will be bulbous; if it is not bandaged high enough, its distal end will be small and shrunken and its proximal portion will retain its normal size. Such stumps fit poorly within the socket of the prosthesis because of the marked variation in circumference at different levels, and must be reformed by bandaging carried out in such a manner that pressure is equal throughout the stump.

Complications Due to the Use of the Prosthesis

The use of the prosthesis may result in mechanical injury to the skin or subcutaneous tissues or may be followed by circulatory disturbance. These complications usually arise because the limb has not been properly fitted or aligned, or because the patient is not applying the stump sock or the artificial member correctly. The fitting and alignment of the prosthesis is the province of the limb maker and the surgeon, and is dealt with in detail in the section on Prostheses; the application of the stump sock and the artificial limb is the task of the amputee and he should be thoroughly instructed in the proper methods, as described previously in this section. Suffice it to say here that the limb, if fitted or aligned poorly, will cause pressure upon points which do not tolerate it well; the sock, if wrinkled, will irritate the stump or, if too tight, will exert undesirable pressure; and the prosthesis wrongly applied will have as dire effects as one which is not properly fitted.

Pressure sores may develop on bony prominences at any point where the socket does not fit. These are first evidenced by a pinkish discoloration of the skin; later, the area becomes dull red, swollen, edematous, and painful, and, as circulation becomes poorer, actual ulceration may occur. Treatment in the early stages is carried out by the simple expedient of proper limb adjustment. If the process has become more advanced, the patient may require a period of rest from the limb until such time as the tissues have returned to normal. If ulceration has developed, excision of the ulcerated area will usually be required; such a procedure must be followed by plastic repair in accordance with the methods used in the final closure of the open amputation stump, for skin grafting or closure

Fig 292—The "roll of flesh" is the result of forcing the stump into a socket that is too small to contain it. The result is an overhanging mass of soft tissue in the adductor region which, in addition to being painful, tends to undergo breakdown and infection if not corrected by early proper fitting. (Walter Reed General Hospital Neg No 4200 1)

by simple approximation of the wound edges will usually result in eventual breakdown under minimal trauma

Bursae over bony prominences are nature's response to friction between skin and subcutaneous tissue, and their inflammation is the result of unusual pressure within the prosthesis They are most commonly found in the below-knee stump over the head of the fibula and the tibial tubercle Treatment for the uninfected bursa consists of removal of the artificial limb, and aspiration followed by wrapping of the stump with elastic bandage For the infected bursa, drainage and chemotherapy are required With the below-knee stump, ischial-bearing may be provided until the bursa has disappeared, but with all others the limb should not be used until the area is again normal Occasionally a bursa will keep recurring and will develop a thickened crepitant sac In such cases, surgery may be necessary, although it should always be approached with great reticence, since the bursa lies in an area subject to pressure, where surgical scars would be likely to break down If it is mandatory, the incision should be placed at points where there is a minimum of pressure, or, if possible, entirely away from the socket

Fig 293 —Bursa over the head of the fibula formed in response to pressure from the prosthesis (Walter Reed General Hospital Neg No 4602 2)

Blisters and **abrasions** are usually the result of small pressure points or roughened areas within the socket, such as places where a leather liner is overlapping, where coarse thread is used to sew a leather socket, or where a slight elevation is present Treatment consists of correcting the defect within the limb and abstaining from its use until the area has healed

Swelling, edema, and **ensuing circulatory disturbances** in the lower extremity stump may be the direct result of the obstruction of return venous

flow by pressure from an ill-fitting prosthesis When the stump shows signs of circulatory embarrassment, the following points should be checked

In the below-knee limb

(1) The sharp posterior border of the thigh corset may press upon the vessels in the upper popliteal region This can be corrected by cutting the back of the thigh corset at a slightly higher level or by making a number of longitudinal slits about an inch in length and about one-half inch apart in the leather which covers the upper popliteal region

(2) The posterior aspect of the socket may compress the gastrocnemius muscle against the lower popliteal vessels if the stump is fitted too tightly Venous stasis can be relieved by enlarging the socket or putting on a thinner stump sock

(3) The third possible source of congestion is at the distal end of the stump At this point the socket should be fairly loose and should not compress the stump in any way If the patient is wearing several stump socks, the extra ones should be removed and leather liners added to the upper portion of the socket Care should be taken to insure that the liners do not extend below the weight-bearing surface, for, if they do, edema and congestion will recur just as though the socket were too small

In the above-knee limb

The anterior rim of the socket may be too snug, so that it compresses the venous and lymphatic channels at the level of the femoral triangle It should be relieved to the point where a finger can be slipped within the socket where it overlies these vessels

In the suction-socket limb

The negative pressure within the vacuum chamber may be excessive and cause transudation of fluid in the tissues and increased capillary breakdown This should be checked with a special pressure gauge If it is excessive, adjustment should be made, if not, the socket, where it overlies the femoral triangle or the popliteal space, should be checked and relieved where necessary

Fresh Fractures in the Amputated Extremity

Fresh fractures may occasionally occur in amputated extremities When they do, the general principles of reduction and immobilization are the same as those underlying the treatment of fractures in any extremity, but there are three factors which influence technique (1) Length is of no moment provided that the end of the stump still lies within a functional area and that no bony prominence or deformity exists which would impair the use of the limb If fracture occurs in the bony segment above the amputation stump, minor discrepancies can still be tolerated provided angulation or bony projections are not present and there is no great difference in the level of knee or elbow (2) Incisions and skeletal fixation cannot be condoned within the area covered by the prosthesis Open reduction within such an area has two serious disadvantages first, it places a scar where it is not readily tolerated, and second, it puts within the stump an internal fixation, be it plate or screw, which forms a pressure point from within upon the overlying tissues as they are compressed by the prosthesis and acts as an irritant to the deeper tissues and bone when the stump is in motion Similarly, closed reduction with the use of pins or wires in the stump

is undesirable for the skin about the points of entry and exit often heals by scar and becomes fixed to the underlying bone A further danger which lies in open reduction or the use of skeletal fixation is the likelihood of disrupting the terminal filaments of the nerves as the incision is made or the wire inserted, and the subsequent loss of sensation to the stump In intra articular fractures with displacement of the fragments, open surgery is justified where it is anticipated that closed treatment would not give satisfactory joint function, for the use of the artificial limb is not compatible with minimal joint motion In the area which is not to lie within the socket of the limb, i e, the segment of the extremity above the amputation stump, open treatment is permissible in many cases, but even there closed reduction without fixation is preferable if the wearing of a proximal corset is in any way anticipated (3) Early mobilization of joints should be carried out within the limits of sound treatment, for at the risk of repetition I wish to restate the fact that the limb cannot be satisfactorily used in the presence of stiff joints

IX. THE MECHANICS OF NORMAL AND AMPUTEE GAIT

Human locomotion presents a profusion of mechanical minutiae which, taken together, result in the smooth, even, graceful motion of normal gait. Toward this final pattern the lower extremities, and the trunk and upper extremities as well, contribute. Individually, each lower extremity may be considered as a system of articulated levers which are acted upon by the dynamic force of the muscles and the static forces of gravity and inertia. Together, they present a complex series of interrelated physical phenomena undergoing constant flux with each change of position of the limb. The synchronous motions of the trunk and upper extremities aid in the balance and rhythm of forward progression by constantly positioning the body at a point where the most effective use can be made of the center of gravity. Fortunately, human evolution has resulted in a streamlining of the mechanical structure of the body so as to effect a remarkable conservation of energy and still provide the two basic requirements for gait, stability and mobility. Stability is essential if balance and equilibrium are to be maintained during acceleration, deceleration, oscillation from side to side, and up and down motion as each successive step is taken. Mobility, which results from the coordinate action of muscles, gravity, and inertia on the lever system, is required to direct the limb along its course.

The basic knowledge in the field of locomotion has its foundation in the work of the early kinesiologists, Fick, Strasser, the brothers Weber, and Braune and Fischer. To the contributions of these men have been added the more recent studies of Basler, Scheib, Elftman, Schwartz, Hartley and, most of all, Steindler whose researches and observations have been perpetuated as classics of orthopaedic literature. It is not surprising that research and investigation have been scant, for the methods employed have been difficult, time consuming, and expensive both in equipment and personnel. Nor is it surprising that the fruits of these efforts have not been commonly assimilated, for such studies have required complicated mathematical computations, the conclusions of which are lucid only to those with a profound knowledge of physics and engineering. Even for those with such a background it is all but impossible to analyze and evaluate normal gait properly on the basis of the exact sciences because of the difficulty of localizing the constantly shifting center of gravity and because of the human variables of height, weight, pelvic breadth, muscle development, habits, and training. For these reasons this study is limited to a picture story of gait, with supplementary descriptive analyses, which emphasizes the patterns of action which constantly recur in normal individuals and amputees regardless of body build, development, or training. Because of the nature of this work, the pelvis and lower extremity alone are considered.

I wish to acknowledge the gracious assistance of Mr. Gjon Mili, whose unique talents in the field of stroboscopic photography have made this presenta-

tion possible The conclusions drawn from his photographs have been verified through study of ultrahigh-speed motion pictures (300 frames per second)

> *Note* In the analyses which accompany the picture story, all comments are made in reference to the leg which is seen to be uncovered, unless specific note is made otherwise A cycle is considered to be the period from the time the heel of that foot touches the ground, through the single series of actions which take place until it resumes the same position The interrupted white lines were made by lights, fixed to hip, knee, and ankle, and sometimes to the toe and heel, and each line or dot together with its succeeding blank space represents the same length of exposure, thus, the relative speed with which each of those parts was moving can be determined, acceleration being evidenced by a lengthening of the white lines and intervening spaces, deceleration being shown by a shortening or bunching together of the lines and spaces between The small white bumps along the bottom line represent distance markers, and are spaced one foot apart

The Action of the Major Muscle Groups During Gait

The action of the major muscle groups during gait is a combination of contraction to shorten the distance between origin and insertion of the muscle, and a restraining action in which the tendons act as guy ropes to stabilize the joint or allow the gradual lengthening of the muscle in such a manner that jerky, awkward motion is eliminated A study of muscle function is important in gaining an understanding of the mechanics of normal gait, and in recognizing the differences between normal gait and that with the artificial limb Since this is a study only of walking, the participation of these muscles in other activities is not here considered

1 The **gluteus maximus** begins to contract just before the heel strikes the ground, and thus serves to lessen the flexion of the hip at the moment when the knee is brought into full extension It then contracts strongly to bring the body perpendicularly over the lower extremity, and again relaxes as the body falls forward to enter the phases of double support and swing again

2 The **abductors of the hip** function to stabilize the pelvis so that it will remain level, or nearly so, even though the support from the opposite lower extremity is small or absent They begin to come into play at the end of the phase of swing, just before the heel touches the ground, and contract with increasing force as the foot falls to the floor and the upward thrust of the leg is felt as the full weight of the body is superimposed over the supporting extremity As the weight passes forward contraction lessens, and ceases entirely when the phase of double support is reached

3 The **adductors of the hip** maintain the lower extremity near the midline Immediately before, and at the time that the extremity enters the phase of support, they serve to stabilize the hip joint, at the end of the phase of support, they contract to keep the body from drifting from the line of progression When the swing phase is entered they become active to ensure that the limb swings forward along the line of progression and does not drift outward in abduction

4 The **quadriceps muscle** serves the function of preventing sudden or excessive flexion of the knee, and is active immediately before and during the phase of support Just before the heel strikes the ground it holds the knee in extension, as the foot falls to the ground and simultaneous flexion of the knee occurs it contracts strongly to make the flexion gradual and to act as a "shock

absorber' to cushion the jar on the body above, as well as to prevent overflexion and "jack-knifing" of the knee In the terminal phase of support, when the center of rotation of the knee passes ahead of the point of rotation about the metatarsal-phalangeal joints, and the knee tends to bend rapidly through gravity and forward motion of the thigh, the quadriceps is again active to prevent too rapid flexion and create a smoother movement

5 The **hamstring muscles** contract during the last phase of swing when they act as a brake or "check strap" to extension of the knee joint just before the heel strikes the ground Immediately after the heel strikes the ground they aid in stabilizing the knee, and reinforce the gluteus maximus in extension of the hip When the gait becomes rapid, or long steps are taken, the hamstring muscles also come into play during the last part of the phase of support and the first part of the phase of swing to aid in flexion of the knee

6 The **gastrocnemius-soleus muscles** serve to stabilize the foot against dorsiflexion during the weight-bearing period of gait Their action is first noted when the foot rests flat on the floor As the leg rotates to the perpendicular, action becomes stronger and reaches a maximum when the heel is lifted from the ground When the body weight has moved forward to a point where knee flexion is occurring, the power of contraction decreases sharply, to disappear entirely when take-off is completed

7 The **anterior tibial group of muscles** is active to varying degrees throughout almost the entire cycle of gait As the heel strikes the ground a high degree of contraction is present which rapidly becomes maximal as the sole is falling to the ground This peak period of action slows the descent of the foot to the ground and prevents a slapping, jarring effect During the remainder of the phase of support there is mild but definite contraction which aids in stabilizing the ankle joint As the foot leaves the ground these dorsiflexors are again in slightly stronger contraction to enable the foot to clear the ground in the phase of swing, but the tension is not so great for there is no resistance to the motion During the final phase of swing there is also increased action of the dorsiflexors to maintain the foot at right angles in preparation for placing the heel on the ground

8 The **peroneal muscles** are the lateral stabilizers of the foot and ankle As such they are active throughout the phase of support, but their maximal activity occurs just after the heel is lifted from the ground At that time the weight is very rapidly shifted to the first and second metatarsal heads as the foot is tipped inward by the action, first, of the peroneus brevis, then almost immediately following, of the peroneus longus The restraining action of the tibialis anticus and posticus prevents the inward collapse of the foot

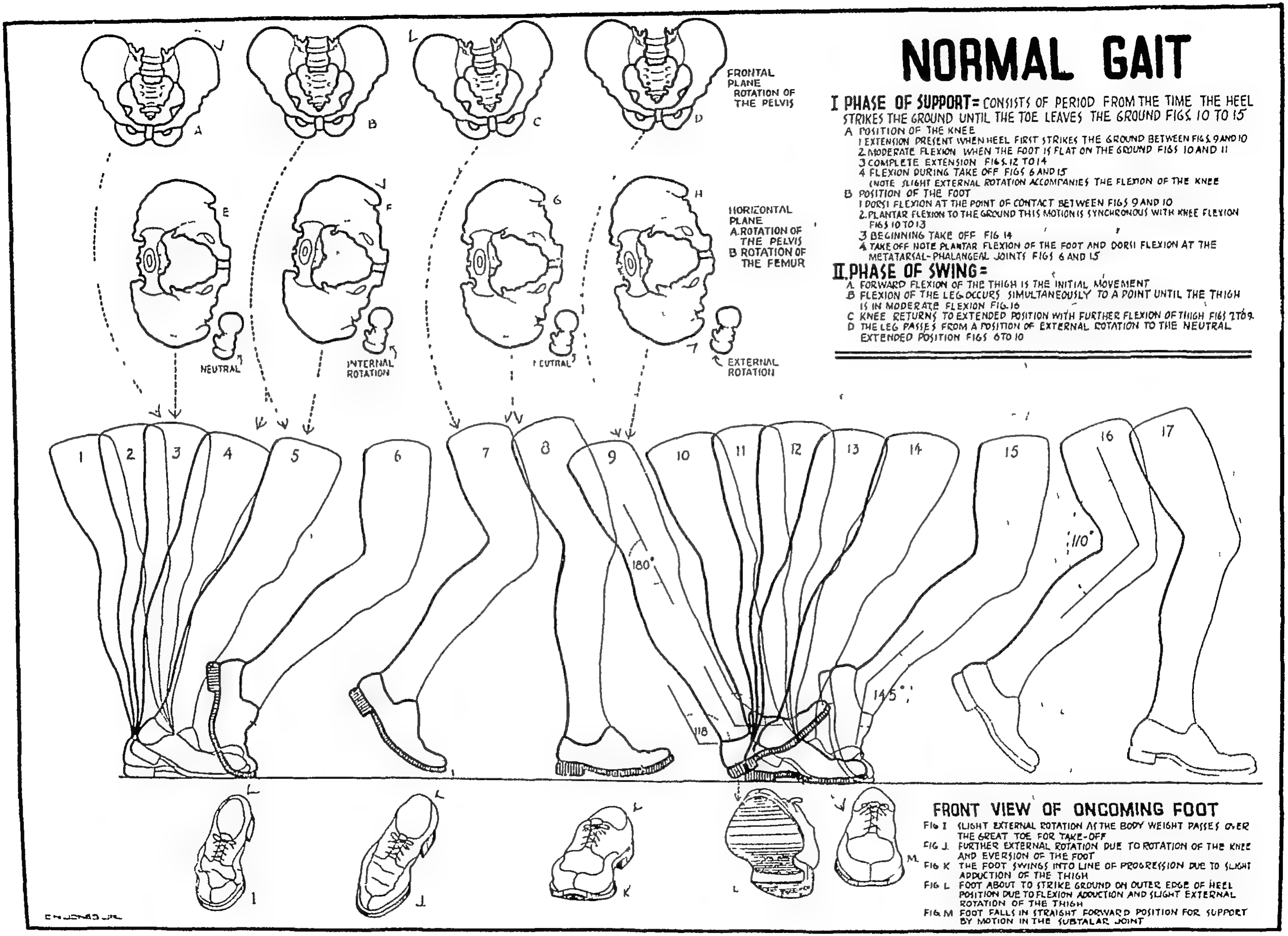
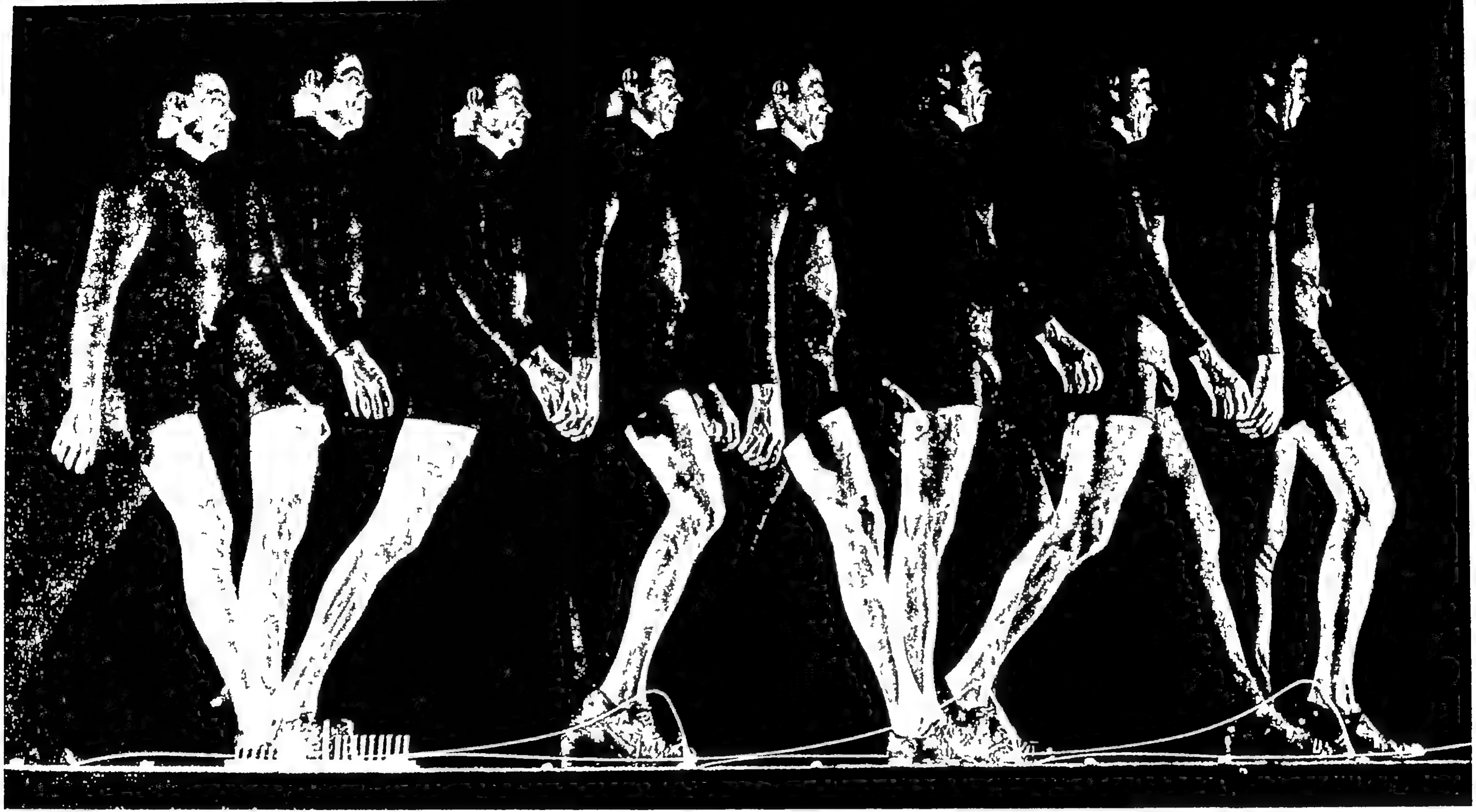


Fig 294 — Normal Gait. The pattern of normal gait as seen from the side view represents a tracing of a projected view of a stroboscopic photograph. Correlated with this are the movements of the pelvis and oncoming foot in the different phases of gait. Normal gait encompasses



Double support — Swing — Support

Fig 295.—Normal gait is divided into three phases. The phase of support is that period of weight-bearing from the time the heel strikes the ground until the toe leaves the ground. The phase of swing is the period in which the foot does not come in contact with the ground. As one extremity is in the phase of support, the other is in the phase of swing, and vice versa, but there are two brief moments in each cycle in which the weight is borne on both simultaneously; such a moment is known as the phase of double support. In normal walking the period of support is usually just about twice as long as that required for the swing phase.

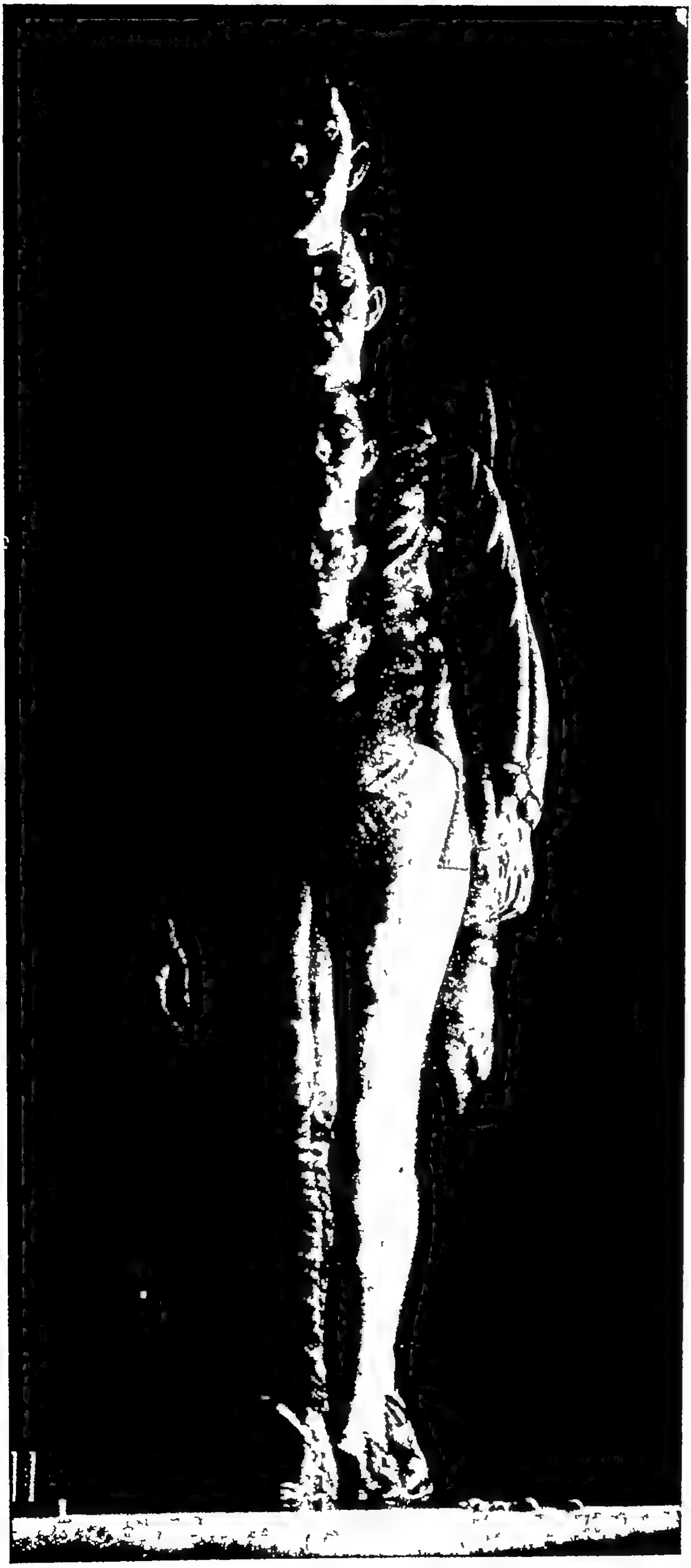


Fig 296

Fig 296—The line of progression This is an imaginary line along which the individual travels In normal straight-forward gait, this line is considered as the shortest distance between the two points between which the individual is passing, and represents a direct line in relation to the sagittal plane of the body when it is in the neutral standing position The inner border of the heel and sole falls along it as the individual moves forward, in this pattern the greatest economy in expenditure of muscular energy is obtained, for the placement of the foot is ideal for stability, the mechanical advantages of the lever system are greatest, the utilization of the forces of inertia are optimal, and the muscle power necessary to attain balanced forward motion is least The joints, in synchronous action in the many planes of motion characteristic of their anatomic peculiarities, provide for a smooth, even, graceful flow of movement For each individual there is a certain pace which is optimal and variations from this ideal, whether they mean faster or slower motion, require the expenditure of additional energy.

At this point I wish to put forward a theory regarding the mechanical action of the extremity during gait I feel that the pattern of human locomotion is dependent upon the position or placement of the foot, and that the action of the muscles and joints, as well as the orientation of the body as a whole, are dependent upon this placement Since balance and equilibrium are best served by having the inner border of the heel and toe fall along the line of progression, this situation is always found in the pattern of action known as normal gait The mechanical construction of human joints is such that synchronous action between them is always present, and should the position of the foot vary from its usual course along the line of progression, a new line is formed to which the body readily adapts itself, i e, should the individual digress from the initial line of progression, the placement of the foot in relation to that line is altered, and an imaginary line drawn along the inner border of the sole and heel in the new position now represents the new line of progression to which the mechanics of the body immediately adjust to afford stability, balance, and mobility for further progress Pathological variations from the normal impose a new set of circumstances, under which the interrelated mechanical forces must establish a new pattern either to place the foot in the normal position along the line of progression or to adjust themselves, for the maintenance of balance and stability, to abnormal placement of that member This new pattern is at variance with the normal and therefore results in a disturbance in the smooth, even flow of normal motion and is evidenced in the awkward motions associated with pathological gait In the following pages, the patterns of action of normal and amputee straight-forward gait are presented and contrasted

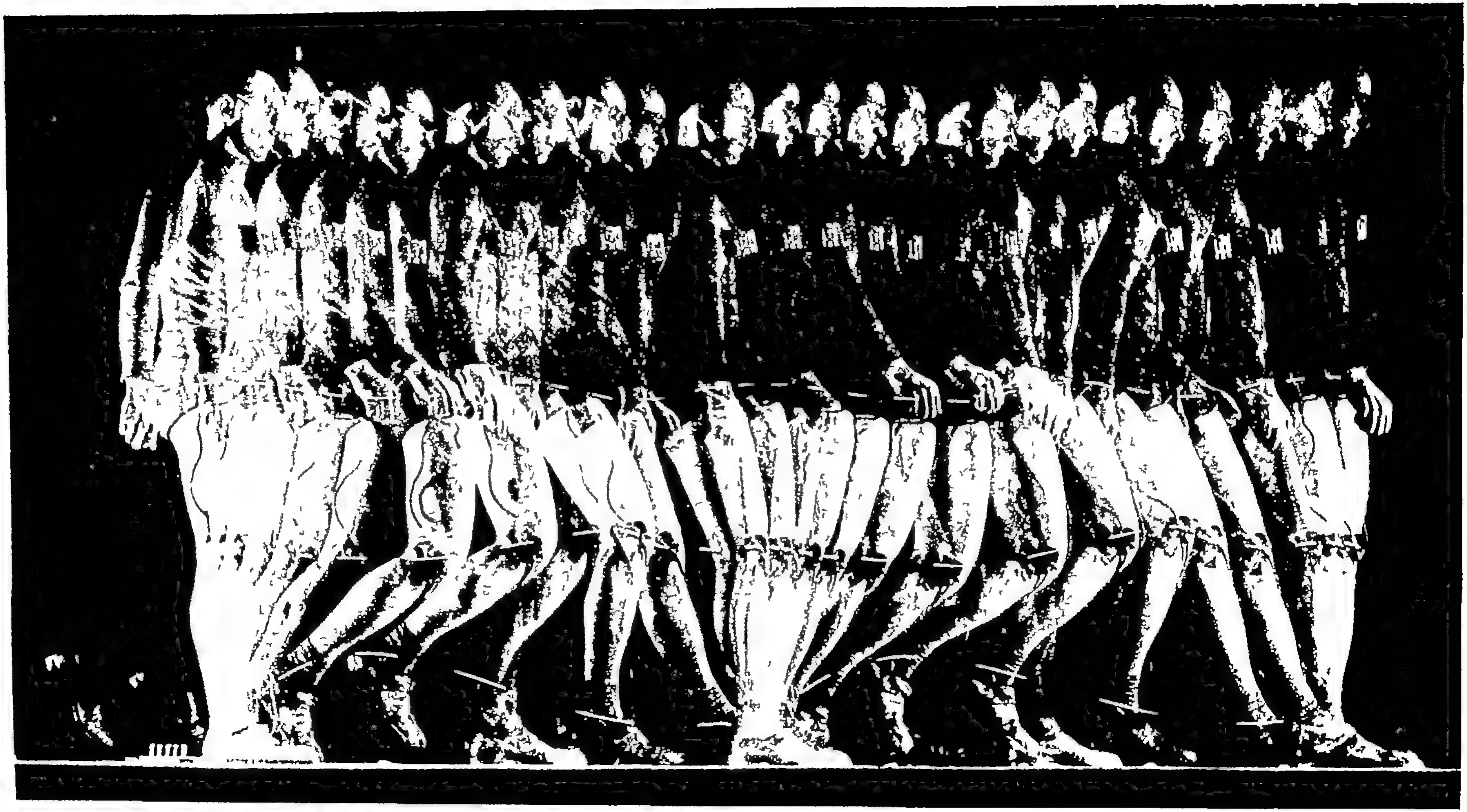


Fig 297

Fig 297.—*Path curves of the hip, knee, and ankle.* This stroboscopic photograph demonstrates the normal pathways of the hip, knee, and ankle joint in the lateral view by means of electric lights powered by flashlight batteries. The light representing the hip joint is placed immediately anterior to the top of the greater trochanter, that representing the knee joint over the center of rotation at the lateral femoral condyle, and the light indicating the ankle joint at the center of rotation of the ankle overlying the external malleolus. The black tape is used to prevent reflection from the surrounding skin. Note that the hip curve reveals two different vertical oscillations during each cycle (as was noted, reference throughout is to the cycle of the uncovered leg), one during the phase of support and one during the phase of swing. The curve is lowest as the heel strikes the ground, rises in a gradual arc as the body rotates over the knee and then over the ankle to reach a point where the center of gravity falls vertically through the hip, knee, and ankle. From this point the curve drops very gradually—not now in the form of an arc with the center of rotation at the ankle joint, as might be assumed at a cursory glance, but rather in a gradual slope, for, as the hip passes into extension, the knee is held in extension and the ankle is fixed by the tendo Achillis so that the center of rotation shifts forward to the metatarsophalangeal joints. This shift of the center of rotation gives the effect of lengthening the extremity, and is maintained until the heel of the opposite extremity touches the ground and a phase of double support is reached. As the phase of swing is entered, the hip curve gradually rises again as the body is levered over the opposite leg, this time in a more even arc both in its rise and its fall. A study of the speed of movement reveals remarkably little variation at this level. There is a slight acceleration as the body drops into both periods of double support, which is due to the effect of gravity, and there is a slight deceleration as the weight is borne fully on a single extremity. In this last respect, when viewed in terms of observation of the cycle of just one extremity, the uncovered one, it will be noted that the deceleration is greater during its own phase of support when that side of the pelvis receives the full force of the upward thrust transmitted through the hip joint, than during its entrance into the phase of swing when the pelvis is rotating forward while the opposite leg bears the weight of the body.

Note now the path curve of the knee. As the heel strikes the ground, the knee is in extension. The line is seen to dip downward slightly as the foot starts its descent to the floor. Shortly thereafter, the knee passes into flexion and the tibia rotates about the ankle joint, causing a slight upward rise of the path curve. As the foot becomes flat on the floor, the tibia continues to rotate about the ankle so that the curve continues upward in a gentle arc until the knee joint, which is now in extension, passes about 15 degrees beyond the perpendicular. At that point the curve starts downward, but its descent is more gradual than its rise, for the center of rotation has shifted to the metatarsophalangeal joints, with the ankle stabilized by the tendo Achillis, and the relative lengthening of the leg has been effected. As the foot leaves the floor to enter the phase of swing, flexion of the thigh begins, and the curve swings sharply upward to reach its highest point as the thigh is in greatest flexion and the knee is about 40 degrees from full extension. The curve then drops abruptly as the knee is straightened, the heel strikes the ground, and the phase of double support begins. This drop is the result of lowering of the whole body in this phase rather than from a jerky motion of the knee.

The path of the ankle curve is less complicated. It drops downward and forward as the heel strikes the ground and the foot falls to the floor, but remains at this point while the extremity rotates over the ankle and the center of rotation shifts forward to the metatarsophalangeal joints. When this has occurred and the foot leaves the ground, the pathway arcs sharply upward and continues in a steep curve until the knee reaches full flexion and the thigh is beginning to flex. From this point the path curve swings downward as the knee extends. It rises slightly as full extension is reached, but drops again abruptly as the heel strikes the ground.

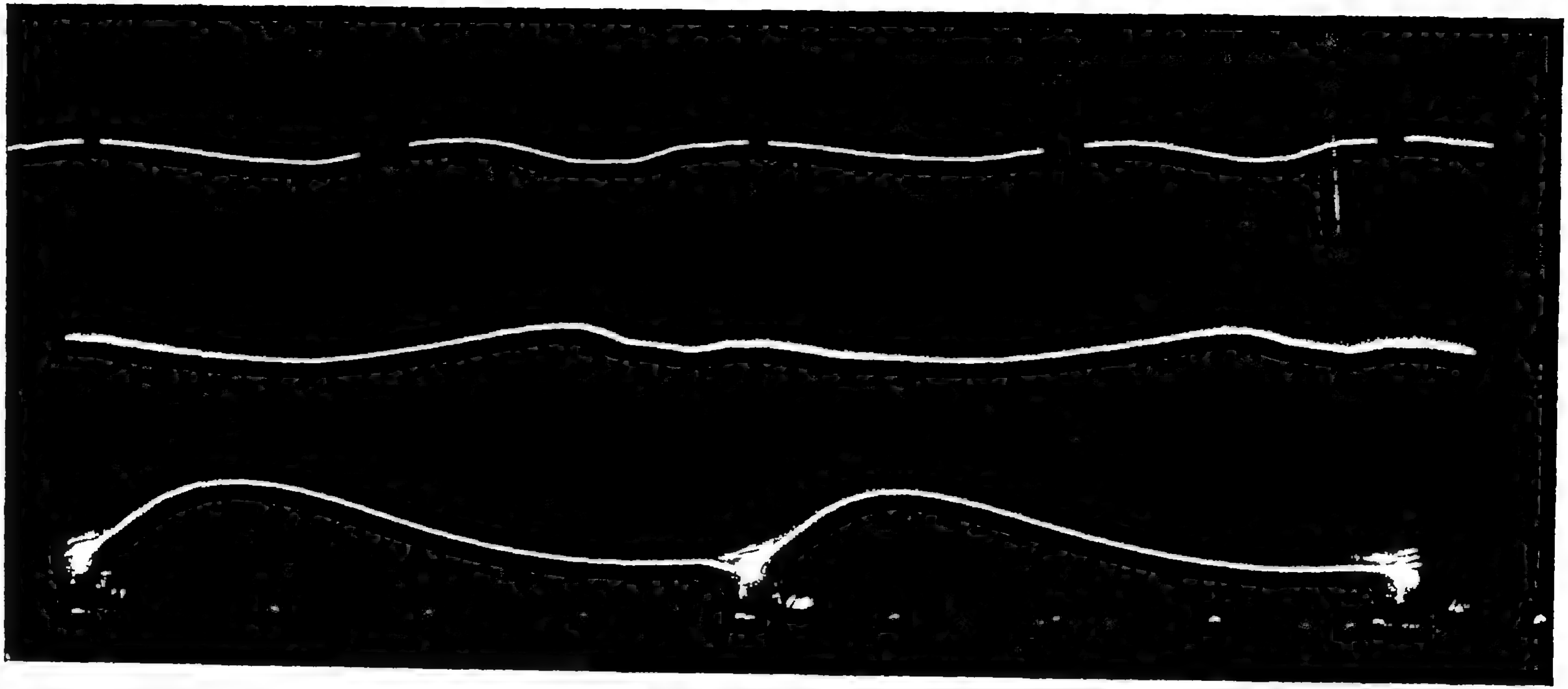


Fig 298 —Path curves of the hip, knee, and ankle, in the same case, as demonstrated by a time exposure with constant lights Interruptions in the path curve were caused as the arm, swinging free during gait, passed between the light and the camera lens

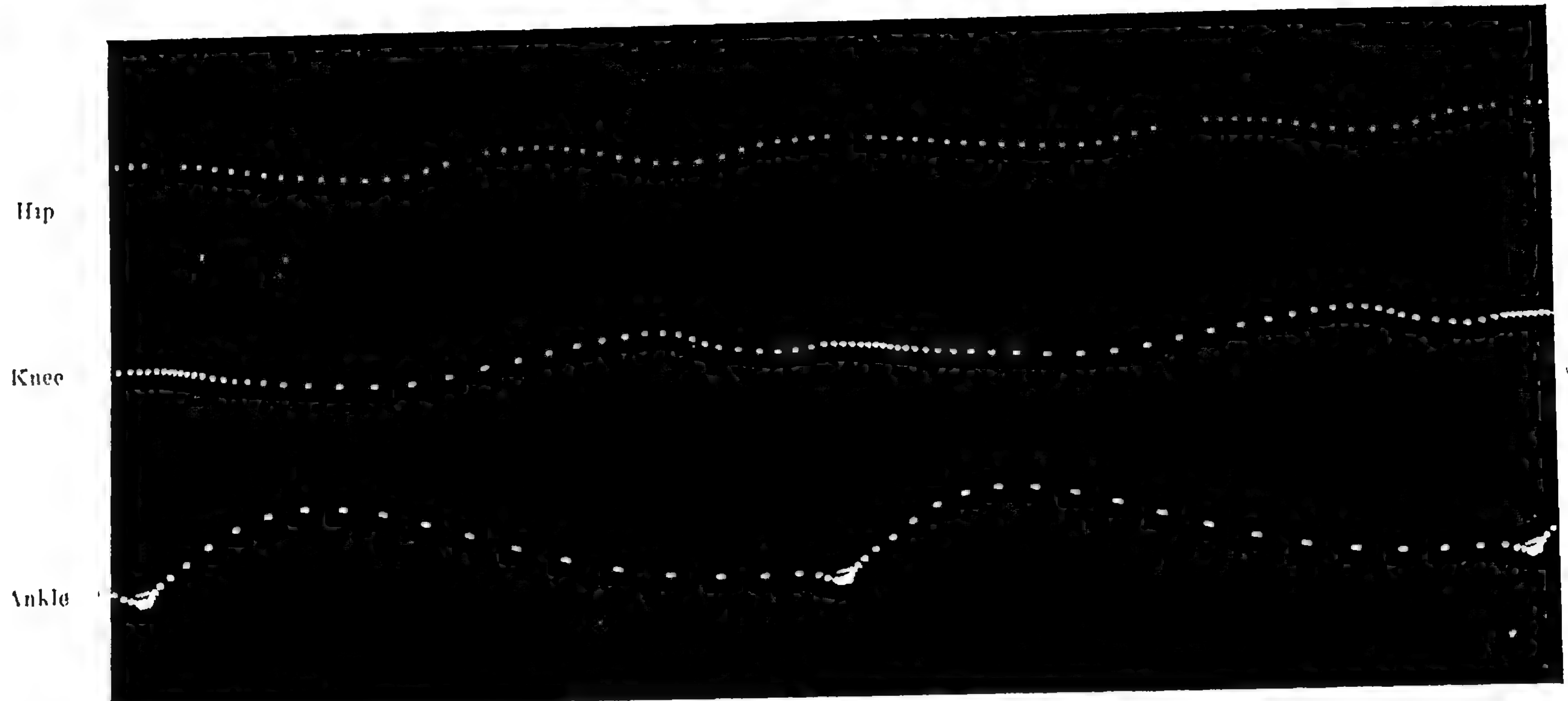


Fig 299.—Path curves of the hip, knee, and ankle, in the same case, indicating the speed of progress The light is interrupted in such a manner that each white dot with its adjacent dark space is equivalent to one-thirtieth of a second

Fig 300

(a) *Flexion and extension of the hip joint*

When the heel first strikes the ground (*9*) the hip is in the position of flexion. It immediately passes into further flexion with the simultaneous bending of the knee and plantar flexion of the foot (*1*) so that its maximal flexion during the phase of support is reached at the time the foot is flat on the ground. From there flexion gradually decreases until the body weight is superimposed directly over the ankle (*6*). (At this point the knee joint is locked in extension and is stable.) As the heel lifts from the floor and the body moves forward, extension of the hip continues until it reaches its maximum during the double phase of support when weight is borne equally on both extremities (*7*). As this point is passed the knee and hip undergo rapid flexion which is aided by the final push-off of the great toe (*3*, *8*). The maximum

flexion which is reached during the phase of swing occurs at the point where the tibia is perpendicular to the floor (1). Immediately before greatest flexion is reached, the speed of forward motion of the thigh is slightly decreased which gives the lower leg time to catch up with the thigh and which, in conjunction with a slight decrease in flexion of the hip in the very final phase of swing (5), allows the whole extremity to fall to the floor with the knee straight and the foot at right angles as the heel strikes the ground (9).

(b) *The rotary motions of the hip in the horizontal plane*

When the heel first strikes the ground, the hip is in slight external rotation, adduction, and flexion. This position is necessary in order to keep the inner border of the heel along a single imaginary line of progression and accounts for the fact that the greatest wear on the heel of the shoe is usually lateral to the midline. Although in external rotation to the pelvis, the femur is in neutral position with regard to the line of progression because of the forward rotation of the pelvis which occurs to accommodate the leading leg (9, also Fig. 294, *H*). As the body weight is carried over the extremity during the phase of support, the pelvis and hip joint return to their neutral or standing position. The rotary alignment of the femur still remains neutral as to the line of progression (6, also Fig. 294, *E*). When the hip is in the position of extension for take-off, the thigh lies in internal rotation and adduction. Since the pelvis is now rotated posteriorly to accommodate the trailing leg, the femur still lies in the neutral position with regard to the line of progression. During the phase of swing, the femur gradually returns to the starting position, and the thigh follows along in the neutral position of rotation with regard to the line of progression, although it is gradually turning from slight internal to slight external rotation with respect to the pelvis, as that structure rotates forward.

(c) *Abduction-adduction movements of the hip*

As the heel strikes the ground, the hip joint is in slight adduction, external rotation, and flexion. This movement is sufficient to bring the heel along an imaginary line which represents the midline in the plane of progression. As the lower extremity comes into the vertical position, the hip joint passes into the anatomic neutral position (or, if the gluteus medius is not strong, slight adduction). As the hip passes into extension, the foot again swings toward the imaginary line of progression, and the hip passes into the position of adduction, internal rotation, and extension. As the phase of swing is entered, the hip goes into the neutral position, or, very slight abduction if the opposite gluteus medius is not powerful enough to maintain the pelvis level during the phase of support of the opposite extremity.

(d) *Vertical movements of the pelvis at the hip joint*

The vertical movements of the pelvis are concerned with the upward and downward oscillation normally occurring during gait. The pelvis lies parallel and closest to the ground immediately after the heel strikes the ground when the extremity is in a phase of double support (7, and Figs. 294, *D*, 297, 298, 299). At this time, it usually is slightly lower on the opposite side, for the abductor muscles, unless exceptionally well developed, are not able to maintain the pelvis level in the face of the upward force transmitted from the floor through the supporting extremity on the one side, and of the downward force of gravity on the other side. From this height, the pelvis drops and is again level as the body passes forward and a phase of double support is reached (Fig. 294, *B*). This drop is more gradual than is the rise to the vertical position, since the length of the leg becomes greater as measured from hip to floor because of the shift of the point of rotation from the ankle joint to the metatarsophalangeal joints as the heel rises from the ground (Figs. 297, 298, 299). As the extremity passes through the phase of swing, the pelvis again rises, but since the situation is now the reverse of that when the extremity under discussion was the supporting one, the pelvis is not quite level but is at a slightly lesser height on the side of the swinging extremity. It then drops again to the initial position

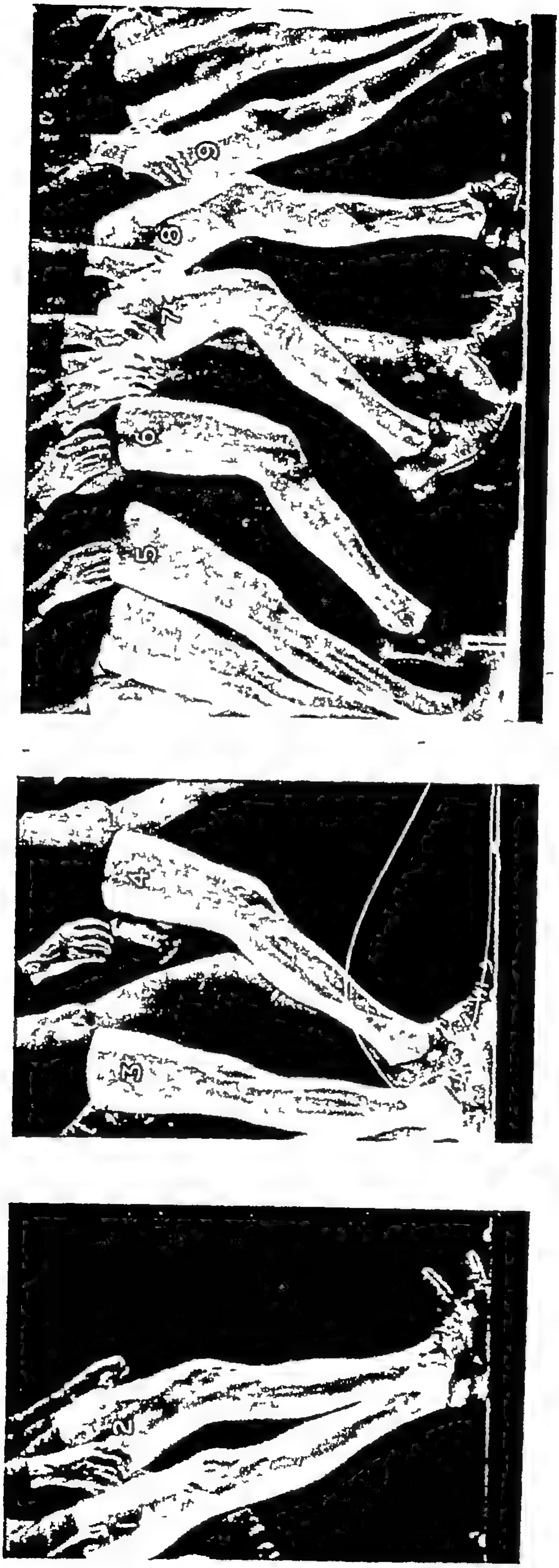


Fig 301

Fig 301 —*The motion of the knee joint* (A composite group of stroboscopic photographs to illustrate the action of the knee joint in the various phases of gait)

A detail of normal gait which contributes greatly to the smooth even flow of the forward motion of the body is the *biphasic extension* of the knee which occurs during the phase of support The knee enters that phase in extension, flexes as the tibia is drawn forward to the perpendicular, and extends again until the entire extremity is upright this series is dependent primarily upon two factors the action of the dorsiflexors which maintain the foot at right angles to the tibia and, therefore, as the foot falls to the ground effect a forward pull upon the tibia, and the tight control of the quadriceps muscle which checks against too great flexion as the tibia reaches the perpendicular, and then effects forceful but gradual extension to lever the body forward, with the knee as the center of rotation, until the weight is superimposed directly over hip, knee, and ankle

As the heel strikes the ground, the knee is in complete extension, and it is in the neutral position with regard to rotation between the femur and the tibia, although in slight internal rotation with regard to the line of progression (*1*) This last is explainable by the fact that in the neutral standing position the transverse axis of rotation of the knee joint lies in the frontal plane, while the transverse axis of the hip and ankle joints are in a position of external rotation to the frontal plane, and that, as the heel strikes the ground, the transverse axis of the hip and ankle joints approximate a position at right angles to the line of progression, which necessarily means that the transverse axis of the knee joint lies in a position of mild internal rotation with regard to the line of progression

As the foot falls to the floor the knee undergoes moderate flexion (*2*) which becomes maximum just before the tibia reaches the perpendicular At the same time that the knee flexes, the tibia rotates externally on the femur so that the foot falls flat to the floor oriented along the line of progression The external rotation is due to the anatomic structure of the femoral condyles the medial femoral condyle is much larger than the lateral so that external rotation of the tibia must occur as the knee is flexed

The knee again passes into extension as the lower extremity reaches the perpendicular (*3*) It now lies again in neutral rotation with the transverse axis of the knee at right angles to the line of progression

As the body moves forward the knee is maintained in extension (*5*) until the point is reached where the axis of rotation of the knee passes forward of the axis of rotation of the foot at the metatarsophalangeal joints, when that point is reached, flexion of the knee is initiated preparatory to take-off (*1*)

As the extremity enters the phase of swing, the knee undergoes a period of very rapid flexion, which is usually maximum at about 110 degrees, and the forward progression of the entire lower leg is speeded up (*6, 7*) As would be anticipated, the tibia becomes externally rotated during flexion, and the foot is thus better able to clear the floor in the forward swing

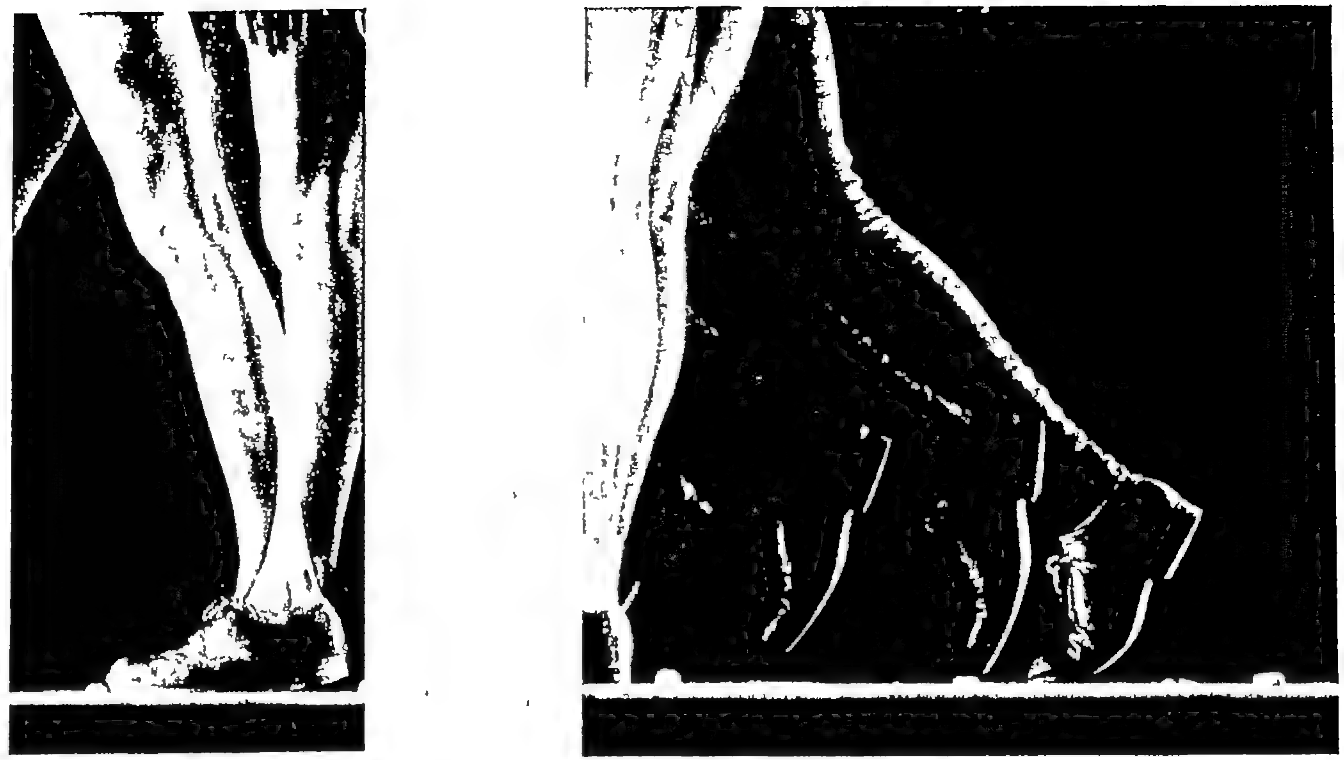
During the latter part of the phase of swing, there is rapid extension of the knee, which occurs simultaneously with a decrease in flexion of the hip in preparation for placing the heel on the ground Hyperextension of the knee is prevented by the action of the hamstrings, which decelerates the leg in the terminal phases of extension (*8, 9*)

Note the action of the muscles anterior tibial group (*1-9*), the peronei (*4, 5, 7, 8*), the gastrocnemius-soleus (*3, 1, 5*), the hamstrings (*9*),

Fig 302 —*Motion of the foot and ankle*

As the heel strikes the ground, the sole of the shoe is at right angles to the longitudinal axis of the tibia, and weight is first borne on the posterior lateral aspect of the heel The foot falls gently to the ground, the anterior-tibial muscle group serving to retard it and prevent a jerky, slapping motion, as the knee begins to flex and the tibia to rotate forward over the ankle joint The external rotation of the tibia on the femur which occurs during flexion, together with the rotation of the ankle and subtalar joint, allows the foot to fall in its normal position along the line of progression It remains in this position as the knee extends and the extremity passes beyond the perpendicular Since the foot falls to the floor before the tibia reaches a right angle to the ground, it is necessarily in plantar flexion at first, but passes into the neutral position and then into dorsiflexion as the tibia moves forward to pass beyond the perpendicular

At this point the gastrocnemius-soleus becomes active to prevent further dorsiflexion of the ankle joint, and the center of rotation shifts from the ankle joint to the metatarsophalangeal joints, and the heel is lifted from the floor As the body moves forward and knee flexion begins again, there is simultaneous plantar flexion of the foot at the ankle joint and dorsiflexion of the toes at the metatarsophalangeal joints Weight is now carried principally on the heads of the first and second metatarsal bones, the metatarsophalangeal joint is in maximum flexion and the extensor hallucis longus tendon is at its greatest tension The stage is now set for take-off, this occurs as the leg moves forward, aided by a final push from the triceps surae and flexor hallucis longus, and as the weight passes through the great toe The foot now enters the phase of swing As it leaves the ground it passes into slightly greater plantar flexion, but soon passes into dorsiflexion of 90 degrees, to facilitate clearing the ground and remains in relatively the same position until the heel again strikes the ground

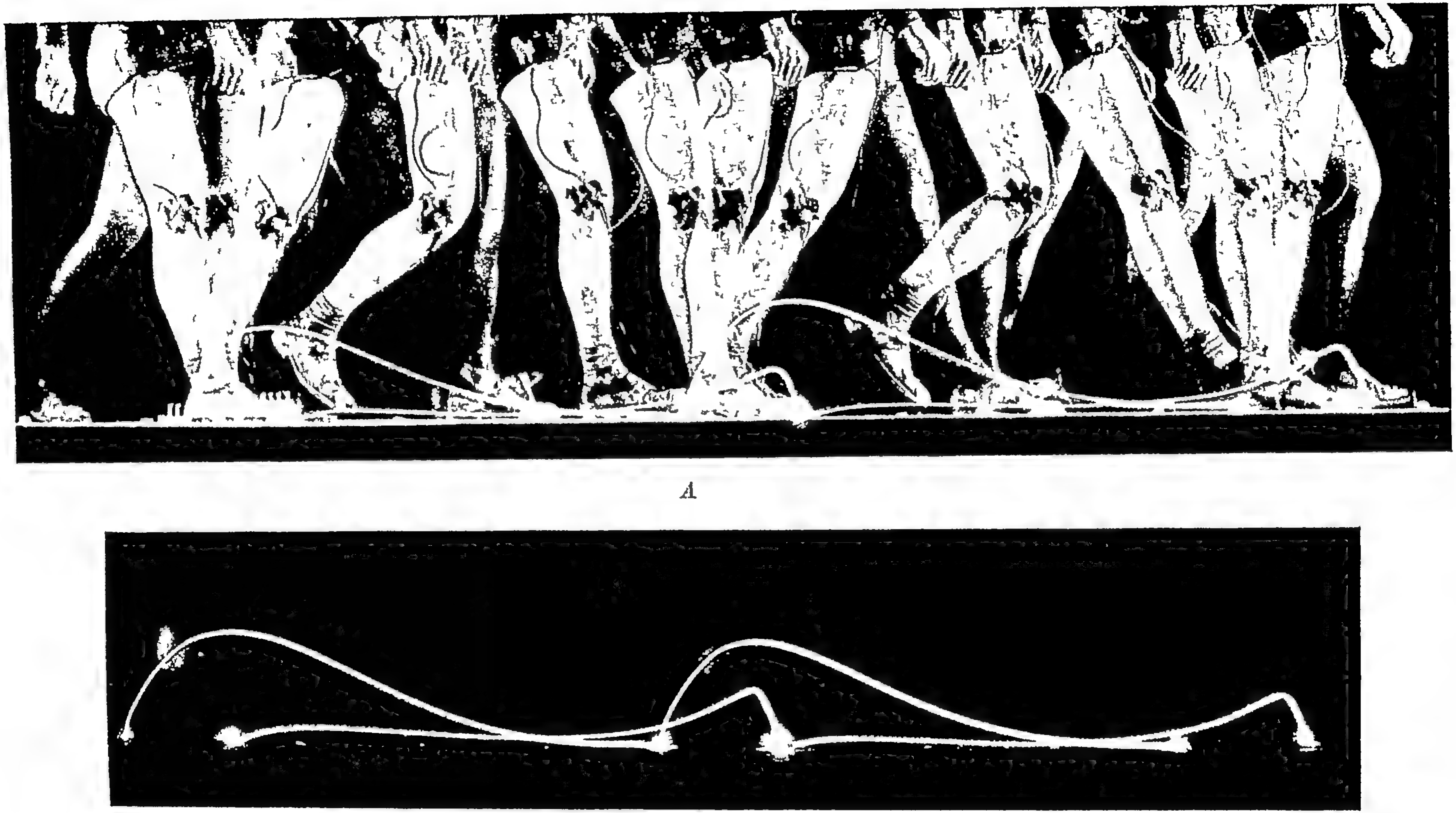


A B

Fig 303 —Take-off

A, When the heel is first lifted from the ground the knee is straight, the triceps surae active, and the center of rotation shifted from the ankle to the metatarsophalangeal joints

B, When the foot deploys for take-off, weight is on the heads of the first and second metatarsal bones, the great toe is dorsiflexed, and there is increased plantar flexion at the ankle joint



A

B

Fig 304, *A* and *B* —Path curves of the toe and heel

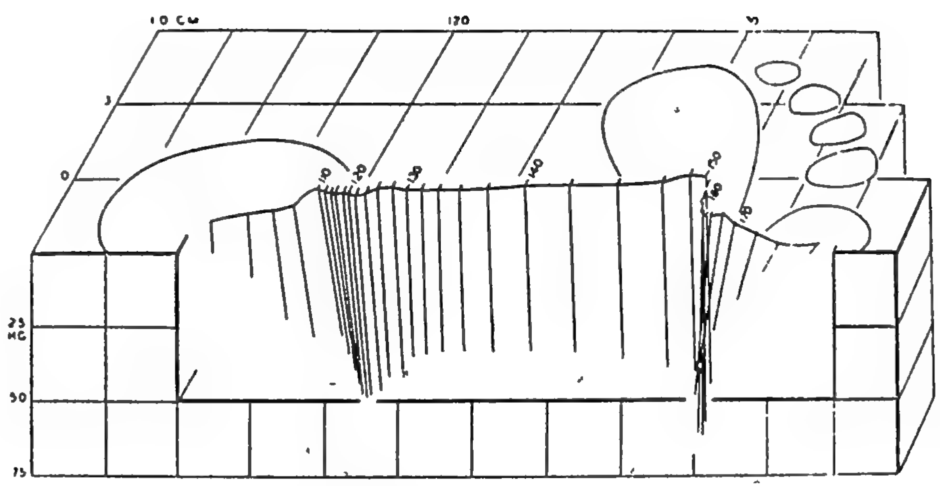
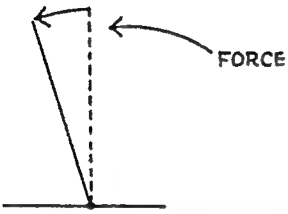


Fig 305 — Reaction of the platform on the foot and its point of application The reaction is shown in two components one in the plane of progression, and the other lateral, in the horizontal plane (Courtesy of Herbert Elftman, Am J Physiol 125 357, 1939)

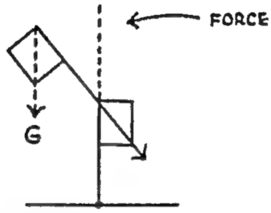
SIMPLIFIED MECHANICS OF THE LOWER EXTREMITY IN GAIT

1 IN THE PHASE OF SUPPORT THE LOWER EXTREMITY ACTS AS A LEVER SYSTEM, LOADED FROM ABOVE, AND WITH ROTATION ABOUT THE FOOT AND ANKLE
2 IN THE PHASE OF SWING THE LOWER EXTREMITY ACTS AS A MODIFIED PENDULUM SUPPORTED FROM ABOVE.

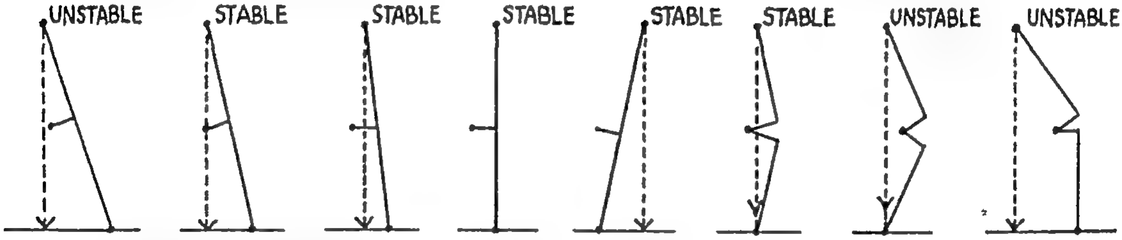
THE LEVER SYSTEM



A A SIMPLE LEVER ACTS LIKE THIS WHEN FORCE IS DIRECTED FROM THE SIDE

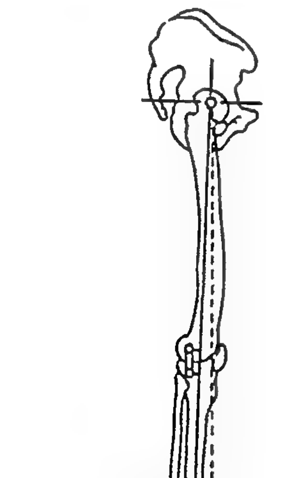


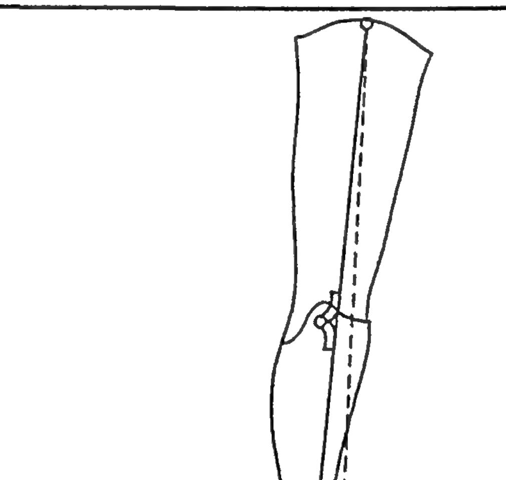
B AN ARTICULATED LEVER SYSTEM ACTS LIKE THIS.



C AN ARTICULATED LEVER SYSTEM WITH AN OFFSET HINGE, LIKE A DOOR HINGE, LIMITS MOTION IN ONE DIRECTION AND EFFECTS STABILITY LIKE THIS

IT IS STABLE IN THE UPPER JOINT AS LONG AS THE CENTER OF GRAVITY REMAINS IN FRONT OF THE CENTER OF ROTATION OF THE UPPER JOINT





BOTH THE HUMAN AND ARTIFICIAL LIMBS REPRESENT LEVER SYSTEMS WITH AN OFFSET HINGE AT THE KNEE JOINT IN ADDITION EACH STABILIZES THE FOOT AGAINST DORSIFLEXION BEYOND 90 DEGREES THE PROSTHESIS THROUGH THE INSTEP BUMPER, AND THE HUMAN FOOT THROUGH THE TENDO ACHILLES

Fig 306

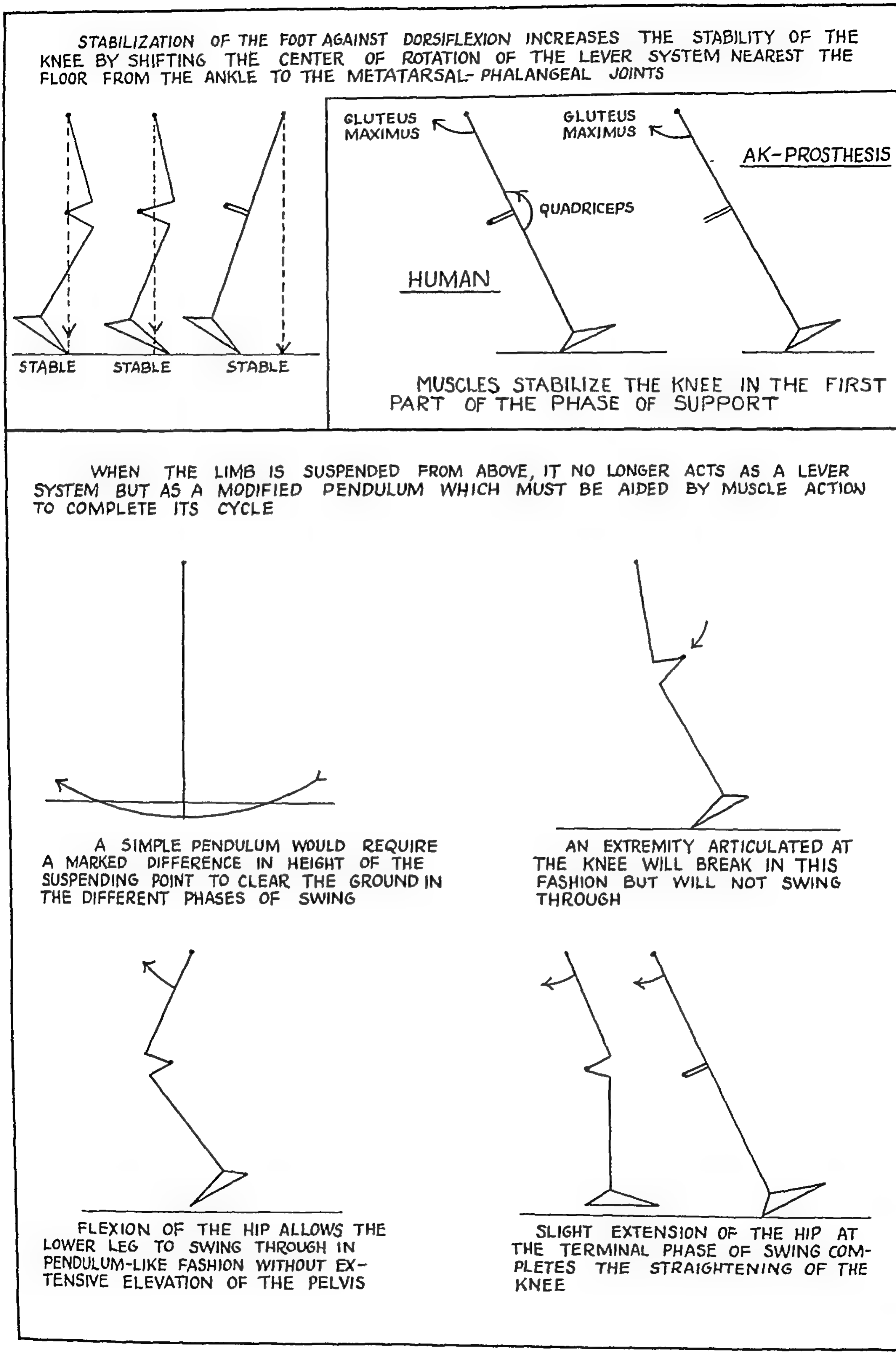
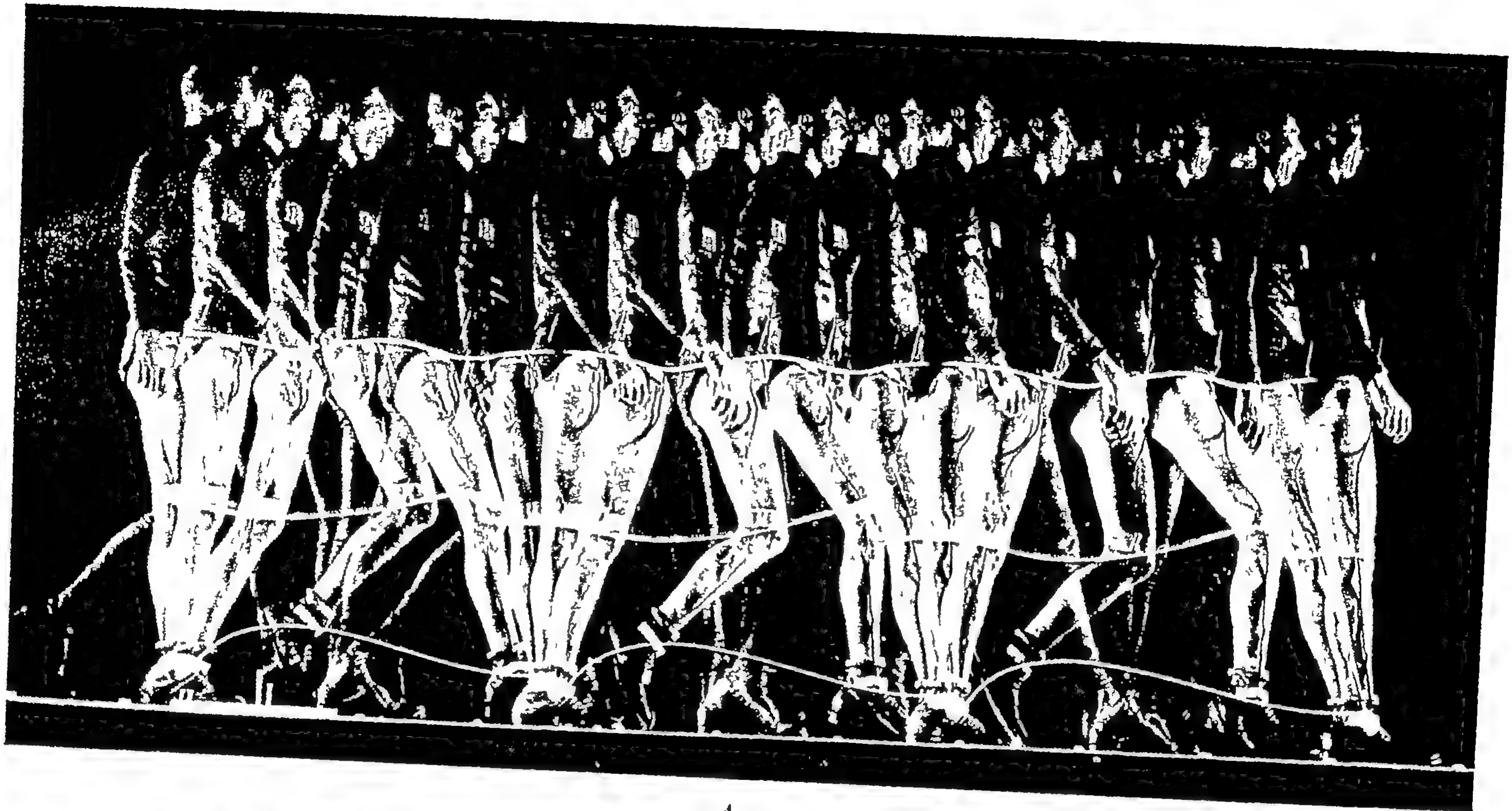
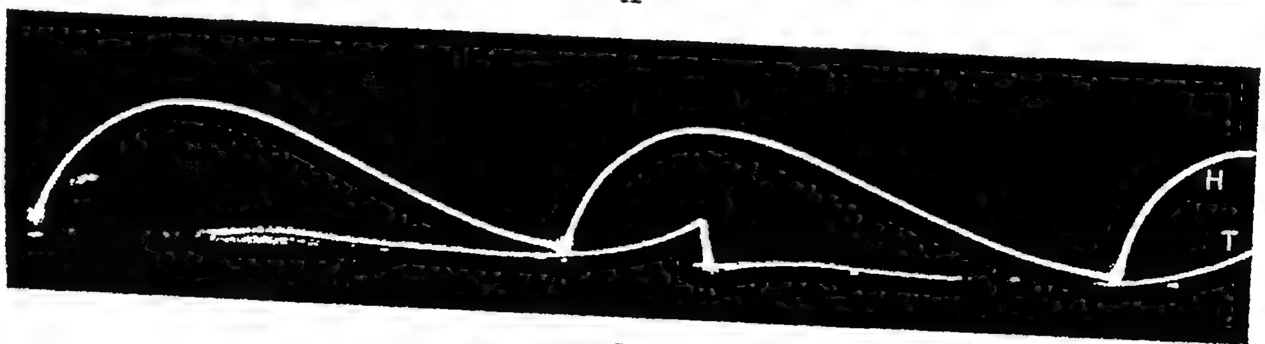

STABILIZATION OF THE FOOT AGAINST DORSIFLEXION INCREASES THE STABILITY OF THE KNEE BY SHIFTING THE CENTER OF ROTATION OF THE LEVER SYSTEM NEAREST THE FLOOR FROM THE ANKLE TO THE METATARSAL-PHALANGEAL JOINTS
STABLE
STABLE
STABLE
GLUTEUS MAXIMUS
GLUTEUS MAXIMUS
AK-PROSTHESIS
QUADRICEPS
HUMAN
MUSCLES STABILIZE THE KNEE IN THE FIRST PART OF THE PHASE OF SUPPORT
WHEN THE LIMB IS SUSPENDED FROM ABOVE, IT NO LONGER ACTS AS A LEVER SYSTEM BUT AS A MODIFIED PENDULUM WHICH MUST BE AIDED BY MUSCLE ACTION TO COMPLETE ITS CYCLE
A SIMPLE PENDULUM WOULD REQUIRE A MARKED DIFFERENCE IN HEIGHT OF THE SUSPENDING POINT TO CLEAR THE GROUND IN THE DIFFERENT PHASES OF SWING
AN EXTREMITY ARTICULATED AT THE KNEE WILL BREAK IN THIS FASHION BUT WILL NOT SWING THROUGH
FLEXION OF THE HIP ALLOWS THE LOWER LEG TO SWING THROUGH IN PENDULUM-LIKE FASHION WITHOUT EXTENSIVE ELEVATION OF THE PELVIS
SLIGHT EXTENSION OF THE HIP AT THE TERMINAL PHASE OF SWING COMPLETES THE STRAIGHTENING OF THE KNEE

Fig 307



A



B

Fig. 308

Fig 308, *A* and *B* —Amputation through the distal tarsus

A, In this patient, the amputation is at the level of the distal end of the cuneiform bones immediately above the tarsal-metatarsal joints, the subtalar, ankle, knee, and hip joints are *normal*, and the *prosthesis* consists of a felt piece stuffed into the shoe to fill the space usually occupied by metatarsus and toes Gait is awkward, for the lack of a satisfactory metatarsal base precludes the shift of the center of rotation from the ankle to the metatarsophalangeal joints, and therefore prevents normal take-off and shortens the stride, and the partial loss and subsequent weakness of the dorsiflexors means the absence of biphasic extension in the phase of support, and a lack of dorsiflexion during the phase of swing As the heel strikes the ground the foot, instead of lying at right angles to the tibia, is in some plantar flexion, so that the sole and toe are only slightly off the ground They drop to the floor abruptly, the knee remains extended, and the body rotates forward over the ankle joint, this divergence from the normal gradual drop of the foot, the flexion of the knee, and the rotation of the body over that joint is caused by the absence of the normal restraining action of the dorsiflexors, which eases the foot to the ground and effects a forward pull on the tibia to bring about flexion of the knee As the body moves forward and the extremity reaches a point about 15 degrees beyond the perpendicular, the pelvis begins to rise in order to lift the heel from the floor, for the rockerlike action which results from the normal shift of the center of rotation of the foot from the ankle to the metatarsophalangeal joints is lacking Thus, the phase of support and the stride are both shortened As the extremity enters the phase of swing, the pelvis rises slightly higher and the hip flexes further than in the normal so that the plantar-flexed foot may clear the ground as it swings forward in pendulum-like fashion Immediately before the heel strikes the ground the knee straightens and there is a sharp decrease in the flexion of the hip, thus, the whole extremity drops downward to bring the heel in contact with the ground

B, The *path curve* of the heel (*H*) and toe (*T*) Note the great height from the floor to which the heel is lifted and how closely the toe skirts the ground because of the plantar flexion of the foot Note also that the toe rises to only half its usual peak height as the heel strikes the ground *preparatory to support*

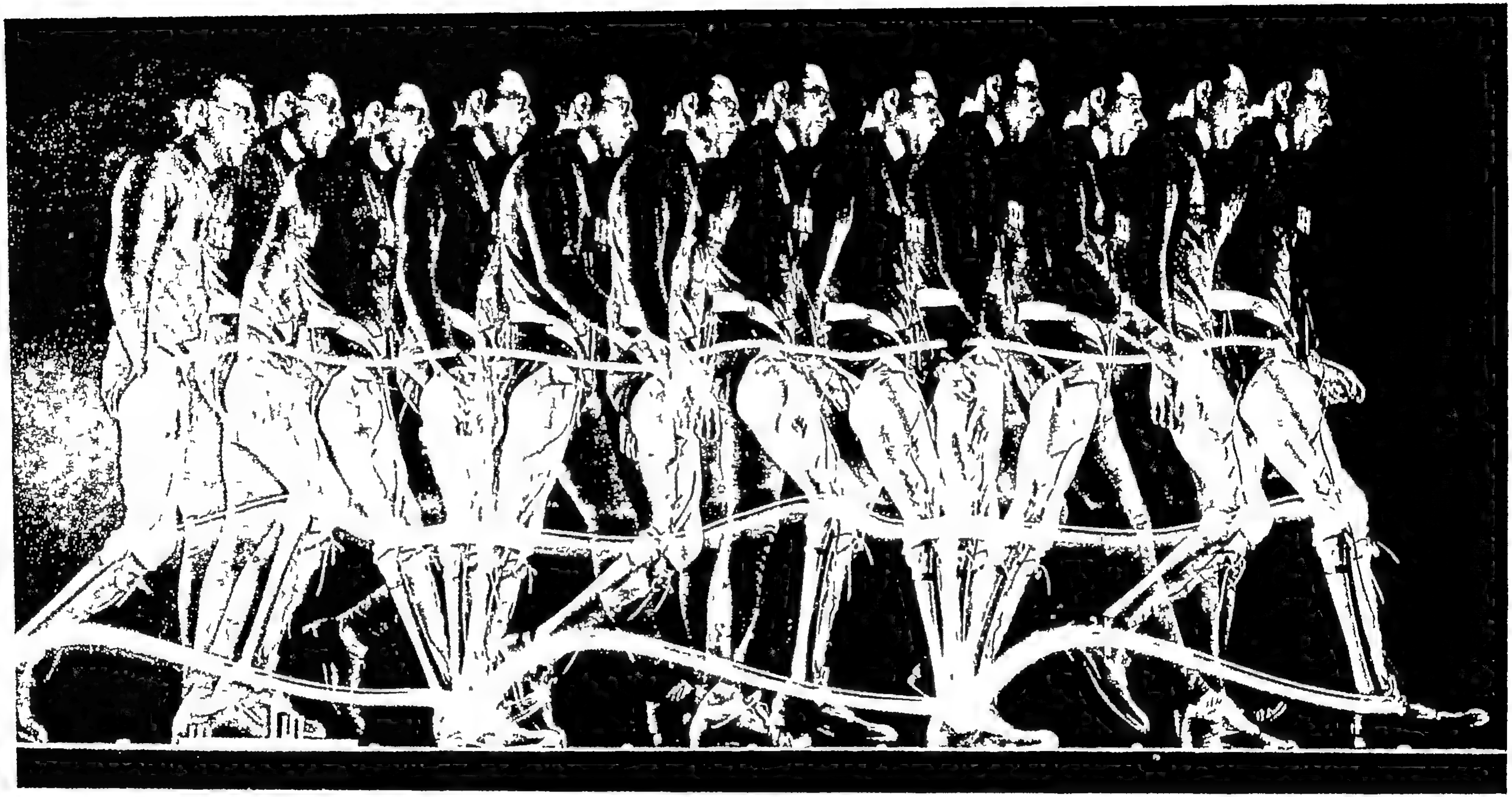


Fig 309 —Syme amputation

This patient reveals a gait pattern which is almost indistinguishable from the normal The chief point of variance lies in the swing phase where the hip is flexed slightly more than in the normal, to allow clearance of the foot which lacks active dorsiflexion The pelvic path curve is normal the knee curve is normal the knee passing through the biphasic extension characteristic of normal gait since it is extended when the heel strikes the ground, then passes into flexion, and finally into extension again as the limb reaches the perpendicular Tibial rotation is present with flexion of the knee, as might be anticipated The path curves of the heel and toe (not shown in this illustration) are normal except that they show a slightly greater height, which is utilized to clear the ground

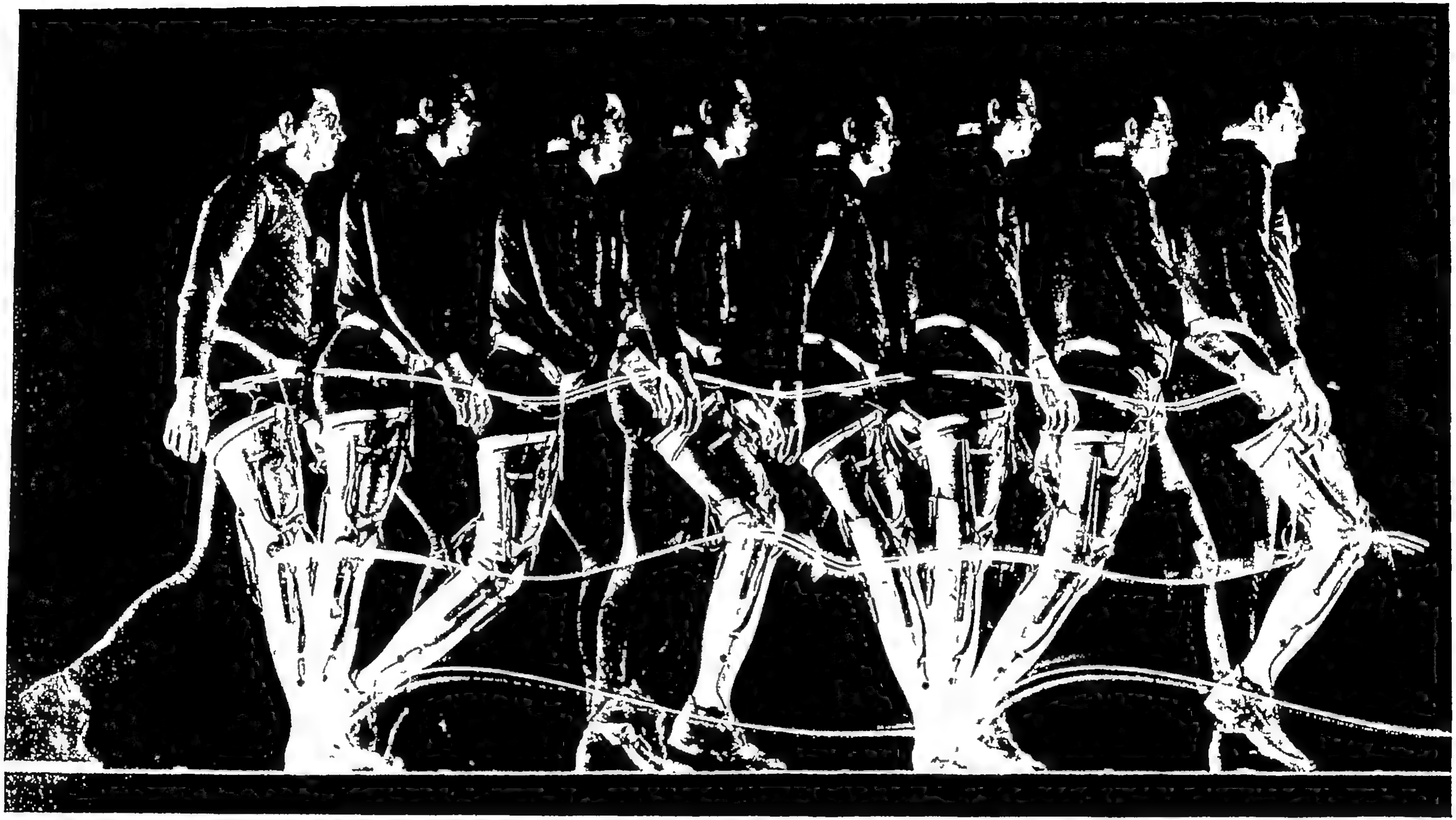
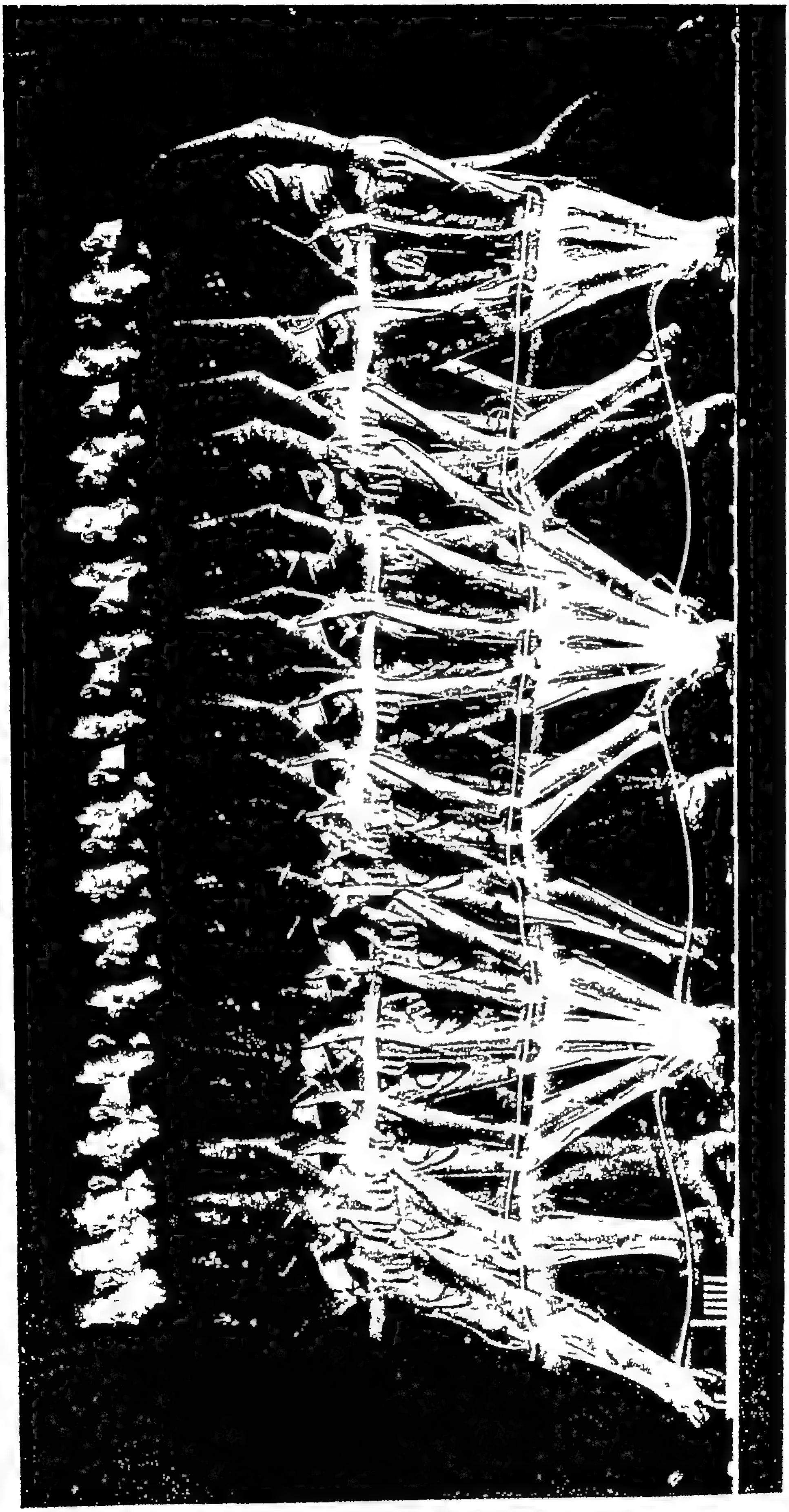
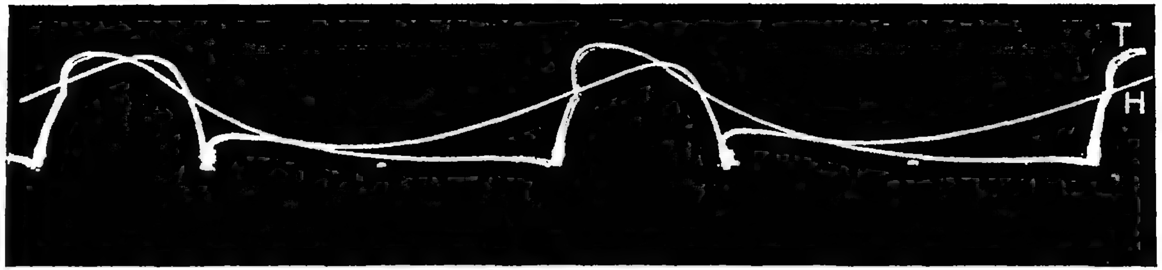


Fig 310 — The below-knee amputation

This well-developed and well-coordinated below-knee amputee, with a stump of ideal length, has excellent gait. It varies from the normal in that the hip flexes slightly more to lift the foot clear of the ground, the skin does not rotate externally during flexion because of the fixation of the knee hinges, and the foot falls slightly lateral to the line of progression. Because of this last, the wear pattern of the shoe is from the midline of the heel to the midline of the toe.



A



B

Fig 311, *A* and *B* —End-bearing amputation of the thigh

A, This patient shows variations from the normal pattern of gait typical of this level A number of important differences are noted In the phase of swing, the elevation of the pelvis is greater than it is in the phase of support, flexion of the thigh increases throughout to reach its maximum just before the heel is to be placed on the ground, the knee reaches complete extension when the thigh is flexed to about 20 degrees beyond the perpendicular As the phase of support is entered, the pelvis drops downward and forward and the hip is extended abruptly to maintain the artificial knee joint in extension, because of a slight overswing of the foot which occurs immediately before this, the extension of the hip causes a backward movement of the whole extremity and gives the effect of "digging in the heel" (the term applied to this process by the limb makers) As weight is borne upon the extremity, the pelvis rises somewhat sooner than in the normal, and the knee of the prosthesis is maintained in extension by the backward pressure of the stump to prevent buckling It will be noted that the action of the hip joint during the phase of swing with this type of amputation shows a significant change from that in the normal or in other amputations of the lower extremity Flexion increases gradually throughout to reach its maximum just before the heel is placed on the ground, when it extends abruptly, in contrast, in normal gaits, maximum flexion occurs while the knee is still in flexion and is decreased to aid in extension of the knee during the latter part of the swing phase The reason for this is readily apparent extension of the knee is complete by the time flexion of the thigh is about 20 degrees beyond the perpendicular because of the rapid forward movement of the free swinging shin piece, as overextension of the knee is checked, the momentum of the forward swing of the shin then carries the entire extremity through to maximum flexion of the hip

The prosthesis for amputation at this level has no rigid fixation to the pelvic belt, and the socket has some tendency to drift downward on the stump under the influence of gravity This makes it more difficult for the amputee to clear the ground with the foot and accounts in some measure for the fact that the extreme rise of the pelvis during the swing phase is found only in the gait of this level

B, Path curves of the heel (*H*) and toe (*T*) The heel, instead of forming its usual gentle arc or upward curvature, is lifted obliquely upward before it enters its forward pendulum-like swing, it then swings smoothly downward, slightly overshooting its mark, and passes sharply backward to plant the heel firmly on the ground The toe swings in a smooth upward slope from the point of take-off, reaches its peak just before the heel is planted on the ground, passes sharply downward and backward, then falls evenly to the floor as the period of support is entered

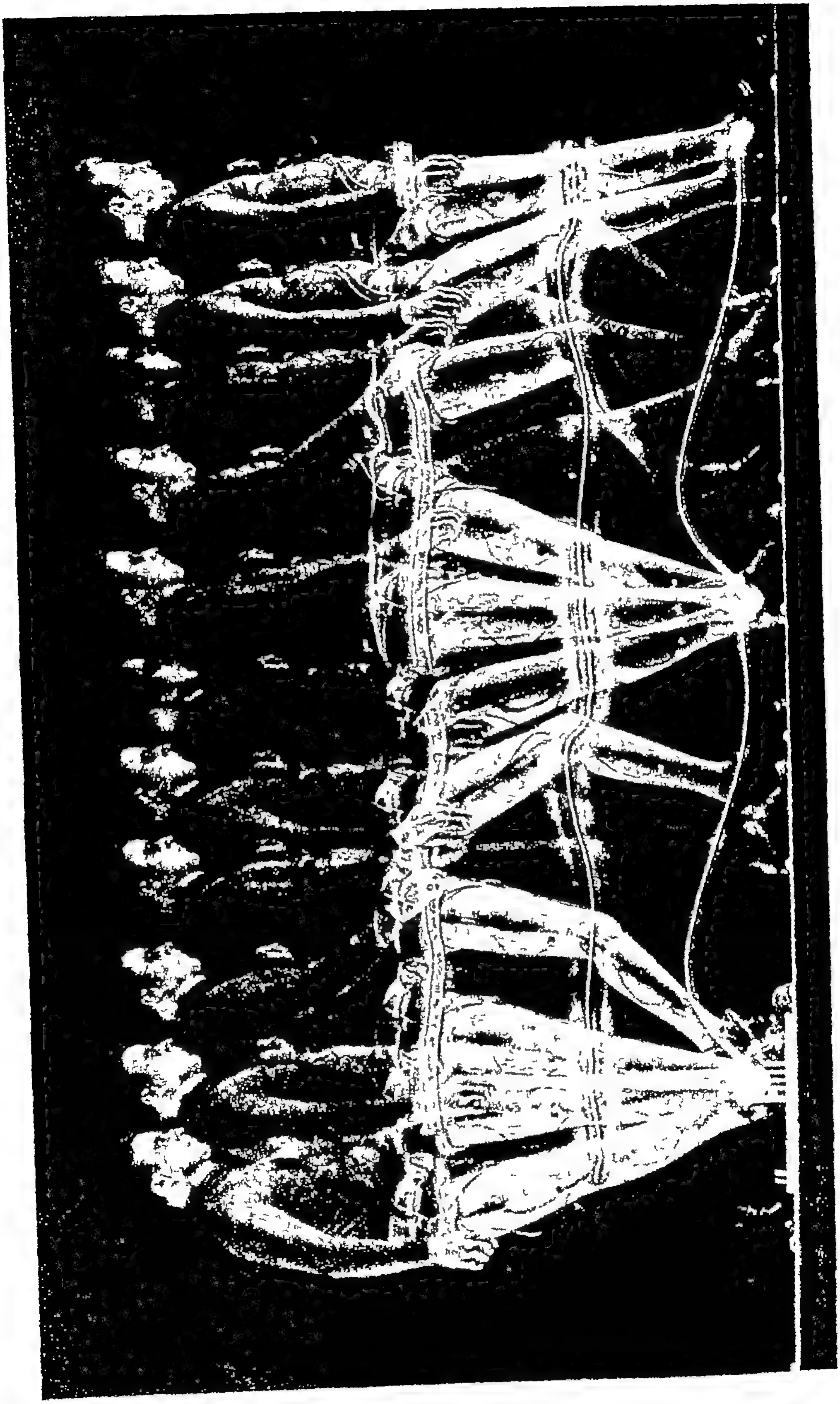


Fig 312 —The ischial-bearing above-knee limb

In a well-constructed and aligned above-knee limb the gait of the above-knee amputee varies little from the normal during the phase of support except that biphasic extension is absent The heel strikes the ground, the foot falls to the floor, the knee remains in extension until it is again suspended from above, and rotation first takes place about the ankle bolt and then about the articulation between toe piece and main body of the artificial foot There is considerable variation, however, in the phase of swing The patient illustrated has a stump which is strong and well-coordinated and the length of which falls within the area of election He exhibits one of the two methods used for clearing the ground during swing—the elevation of the pelvis The path curve of the hip reveals a sudden rise in the pelvis while the hip is passing from extension to flexion, the flexion of the hip approximates the normal and its slight backward motion during its descent to the floor follows a fairly standard pattern Path curves of knee, ankle, and foot (not shown) vary only in the increase in height which is caused by the elevation of the pelvis Clinically, the gait abnormality in this patient was more noticeable than might be assumed from the illustration, since he had a definite "hiking up" of the pelvis as he stepped forward

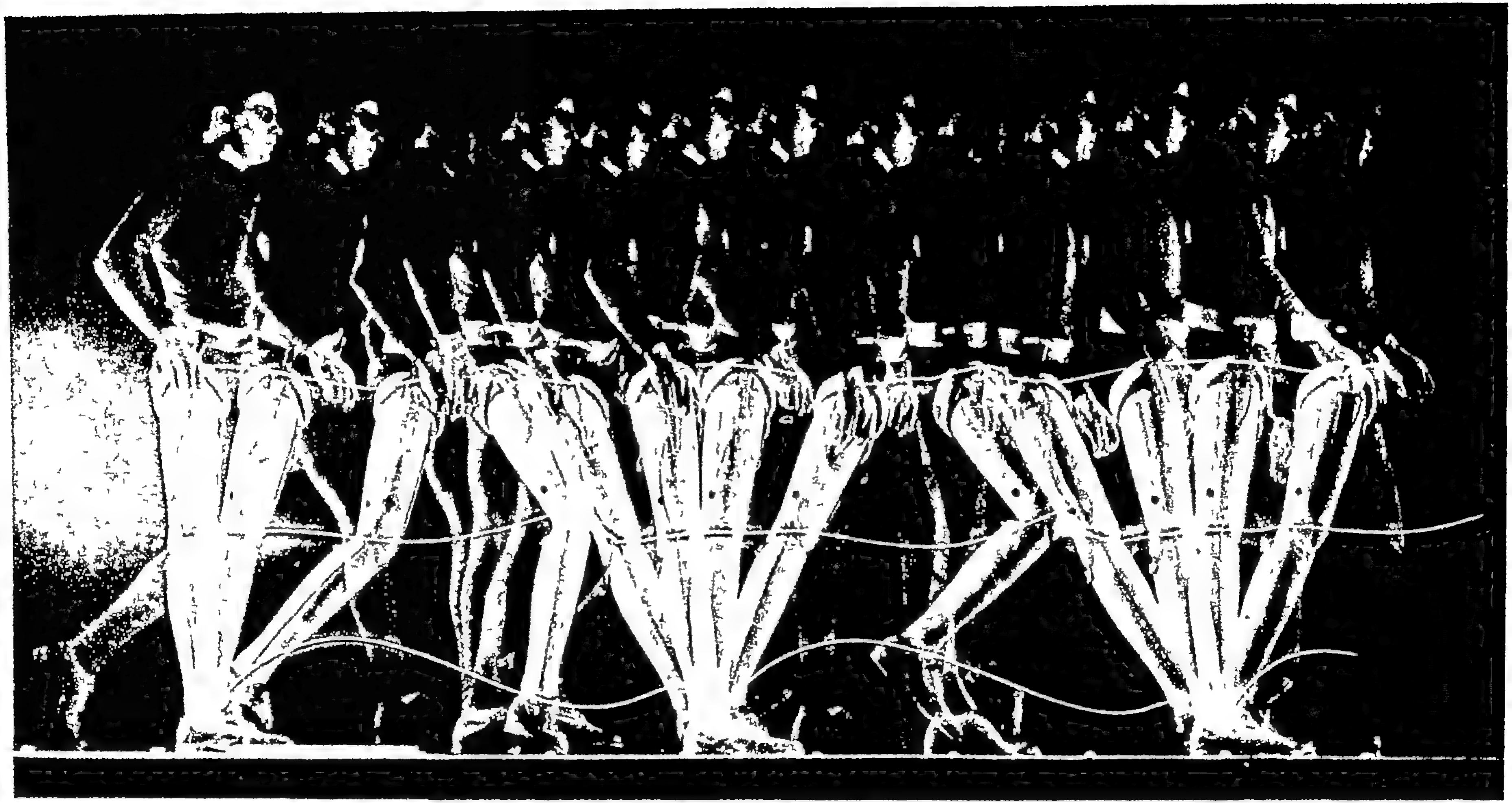


Fig 313 —The ischial-bearing above-knee limb

The gait of this patient who has a stump of normal length, is similar to that of the normal during the phase of support (except for the lack of biphasic extension) as is that of the previous amputee but he utilizes a different technique to bring the foot forward clear of the ground during the phase of swing Here, instead of elevation of the pelvis the hip is flexed forward rapidly, then quickly extended, and the whole extremity is lowered to bring the heel in contact with the ground as the body moves forward The effect on the path curve of the knee is a sharp backward jog immediately after full flexion This type of gait is characteristic of those who prefer the knee friction to be loose so that the shin swings more freely about the knee.

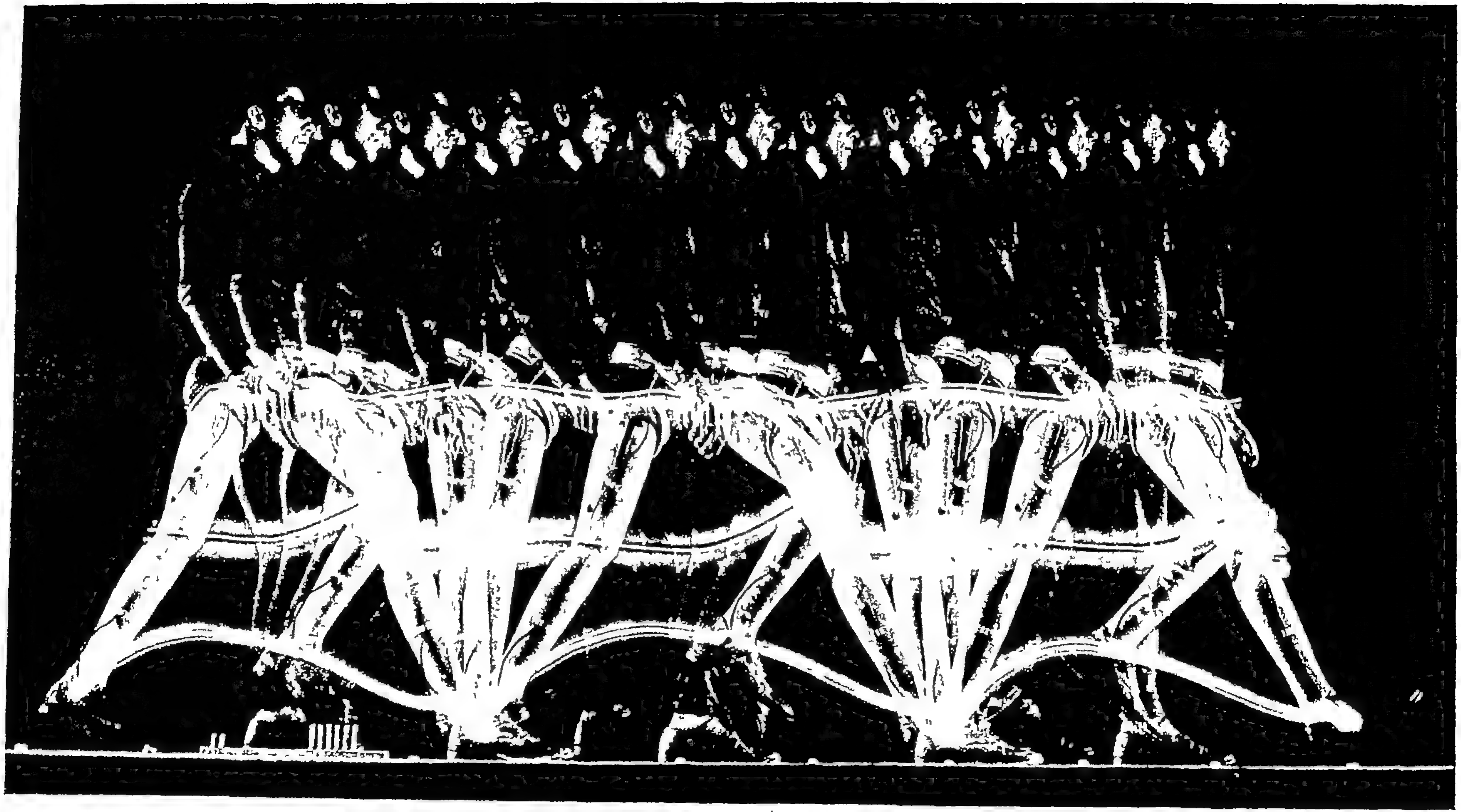


Fig 314—The ischial-bearing above-knee limb an amputee with a short stump and loose knee friction

The patient with a short stump lacks the strong positive control over the prosthesis that is seen in cases with stumps of ideal length He will frequently resort to the type of gait here illustrated in which the stump is used to "throw" the prosthesis forward in a manner which results in marked overflexion of the thigh, and in which the hip is then brought sharply into extension to straighten the knee before the heel

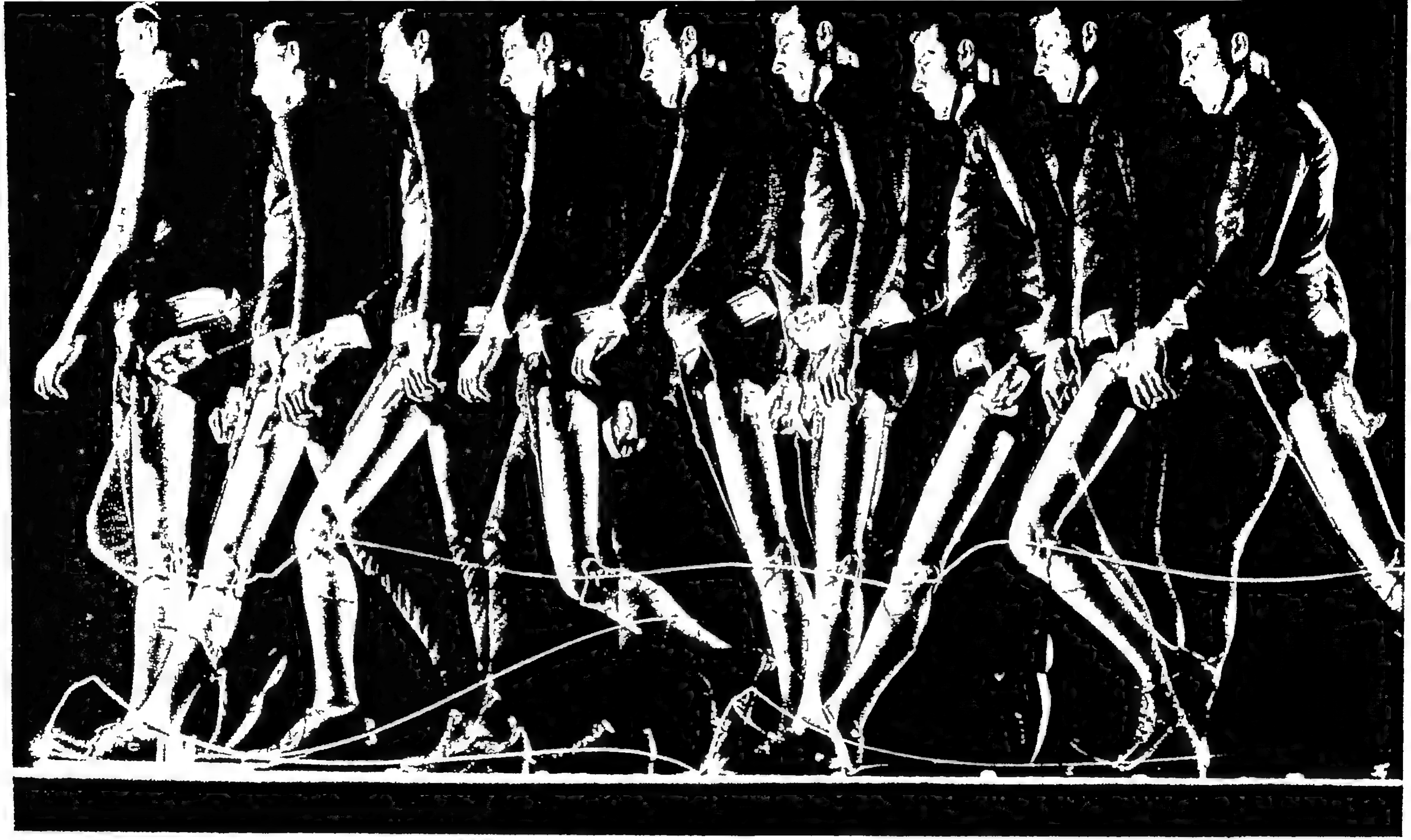


Fig. 317.—The ischial-bearing above-knee limb fitted to a Gritti-Stokes amputation

With a long, powerful, well-controlled lever arm and strong friction mechanism at the knee, this patient has an excellent gait, with no undue elevation of the pelvis or path curve of the knee. Path curves of heel and toe fairly closely approximate the normal. As with all above-knee artificial limbs, the knee passes through a single phase of extension during the supportive phase.

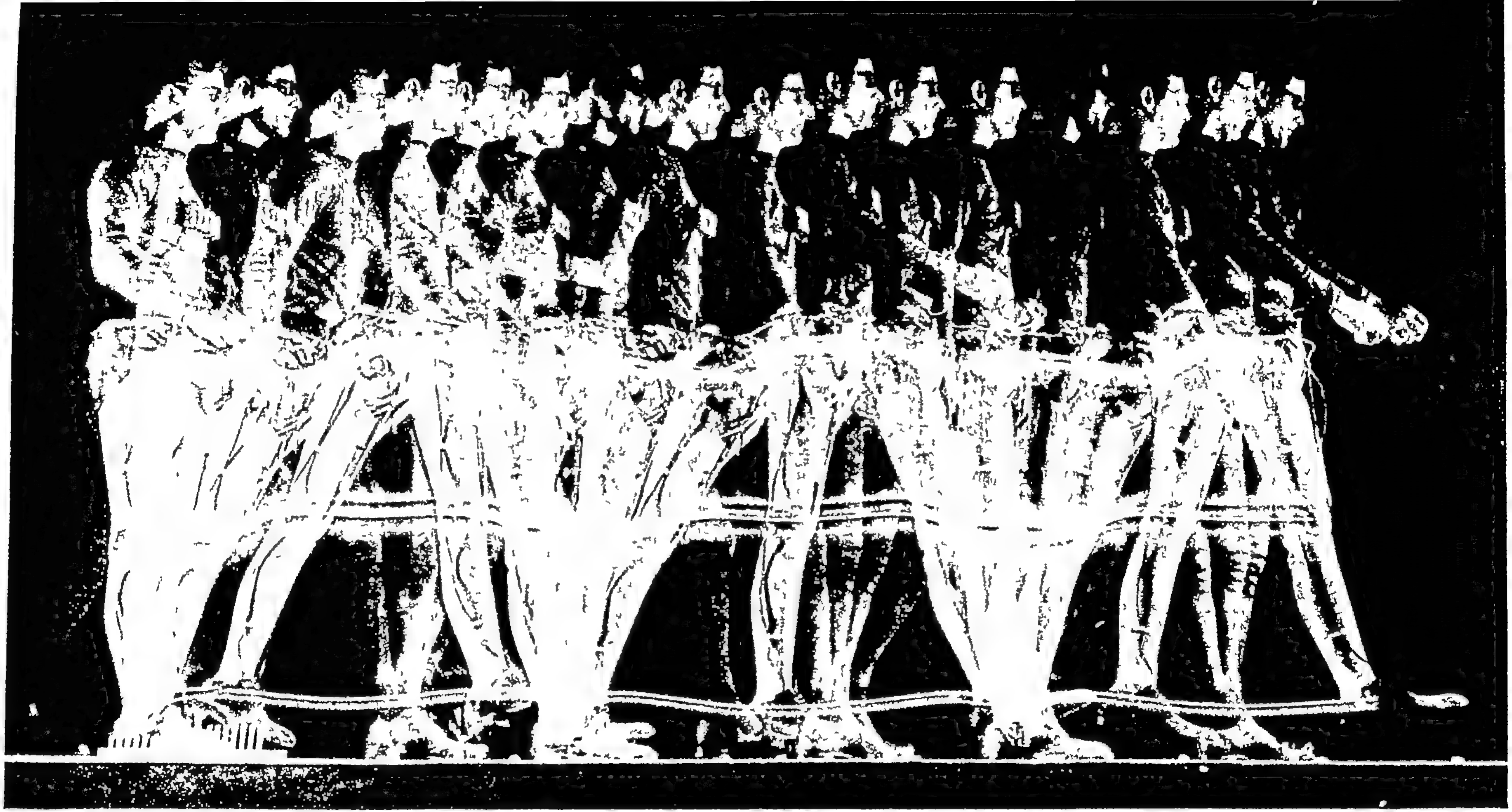


Fig 316.—The tilting-table limb

Here the patient demonstrates the typical gait with the tilting-table limb with the knee locked. The heel is placed on the floor just before the limb reaches the perpendicular. Since no dorsiflexion is present, and since the drop to the floor is nearly vertical, the descent of the foot to the floor after the heel strikes the ground is much less than in other amputations. The body rotates over the limb without movement of the locked hip or knee joints and the foot is lifted sharply from the floor shortly after the heel leaves the ground. In preparation for the next step the prosthesis is then swung forward in wide abduction by elevation and a rotatory movement of the pelvis, and drops sharply to the floor.

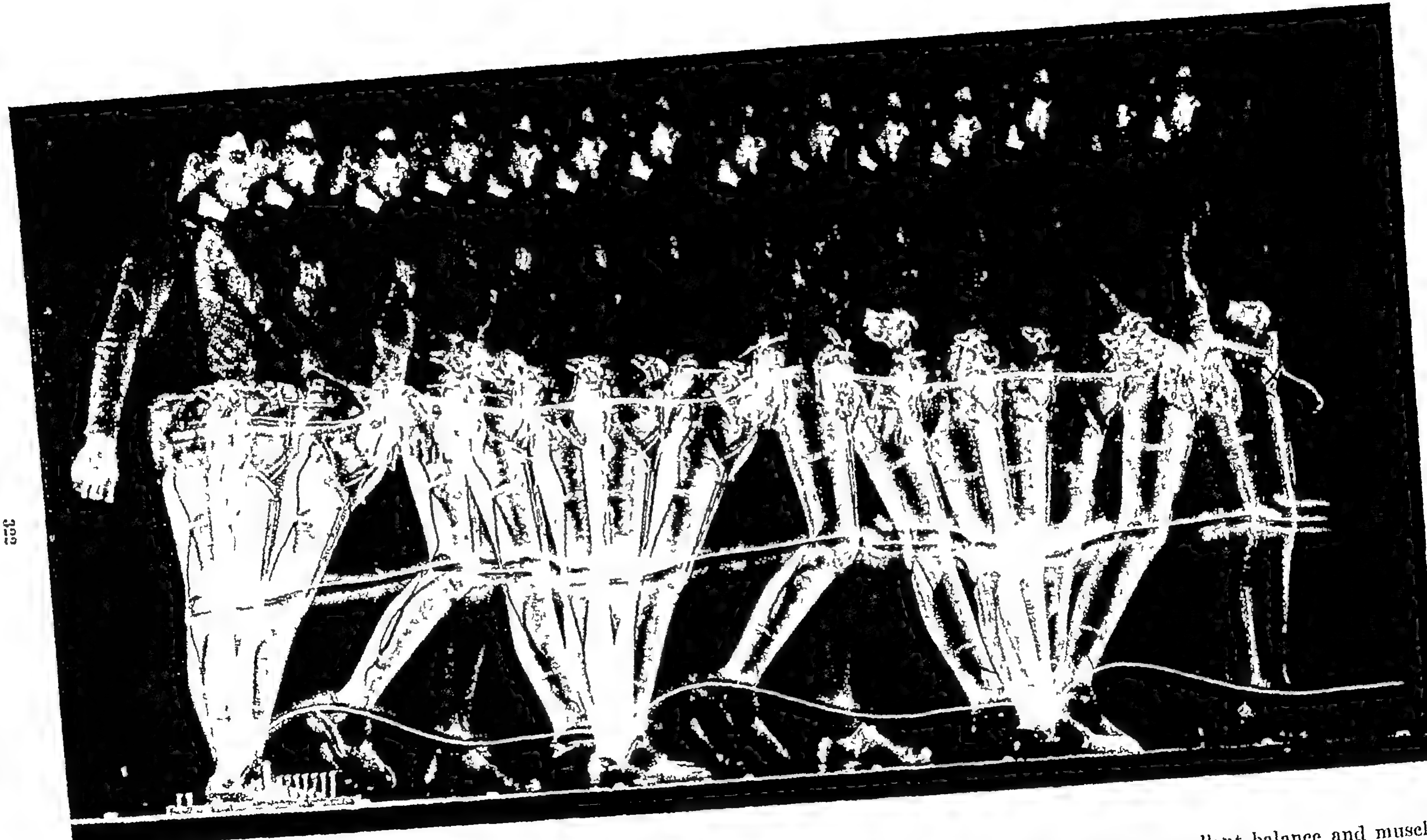


Fig 317 — The tilting-table limb

The same patient is shown here walking with the hip locked, but with the knee unlocked, a feat requiring excellent balance and muscle coordination Although the limb must still be swung forward in moderate abduction, the pattern of action of the foot and knee is more natural and the period of extreme pelvic elevation is shortened so that walking is less tiring

X. PROSTHESES

GENERAL CONSIDERATIONS

An artificial limb, or prosthesis, is a man-made substitute for a missing extremity or a missing portion of an extremity, and, as such, it should as nearly as possible replace the lost part in function and appearance In order to do so, it must be comfortable to wear, meet the needs of the individual, and be able to withstand the trauma of use The prostheses commercially available at the present time are not comparable to the normal extremities, nor in all likelihood will they ever be, but they do meet the above necessary qualifications if they are *adapted to a good stump at the proper time,* and if they are *suitably chosen* and *well fitted*

The time of fitting is a highly important factor As previous chapters in this text have brought out, there are certain criteria as to length, shape, skin covering, and scar placement which the stump should meet in order to serve its purpose and to stand up under use within the prosthesis If, through haste or poor judgment, an attempt is made to adapt the artificial member to the stump too soon, any one or all of these desirable qualities may be lost, for in all likelihood the integument will be unable to withstand the strain of premature use, and breakdown will occur, and in the end revision or even reamputation will have to be done Generally speaking, experience has shown that fitting may be undertaken in eight to twelve weeks following final surgery in the lower extremity, and five to six weeks in the upper extremity This is based upon the lapse considered adequate to allow healing in the normal, healthy, young individual, in the case of the older debilitated patient, or of the one in whom healing has not taken place in the normal manner, it may have to be extended for several months The only safe way to determine the readiness of the stump is to check it thoroughly and be certain that the following conditions are present

1 Sound healing of all surgical and traumatic wounds An immature scar when subject to pressure or friction will usually break down or develop keloid formation

2 Freedom from pain on manipulation Nerve irritability will be aggravated by fitting and may result in pain fixation (Phantom limb pain, unlike pain on manipulation, is not a contraindication to fitting since it usually becomes sublimated after use of the artificial limb)

3 Normal circulation, as evidenced by absence of edema, discoloration, or coolness Poor circulation, when subject to the restrictive influence of the socket of the prosthesis, may become seriously impaired and result in tissue slough and eventual loss of stump length

The prosthesis should be chosen thoughtfully Generally speaking, it should meet the individual needs of the amputee from the standpoint of his stump, his occupation, and his general status and, of equal importance it should be simple in construction and mechanical detail so that frequent repair will not be necessary and adjustments and servicing will not be difficult or expensive More

specifically, it should be composed throughout of materials which are strong, light, and durable, and only those mechanical devices which experience has proved practical should be employed. Through the course of prosthetic development many types of limbs have been designed for each amputation level. To them are constantly being added the fruits of current research. From these divers limbs and devices evolve the so-called "standard" or "conventional" prostheses, those which are a composite of the features which time and experience have proved. These limbs all follow the same basic principles of construction and design but vary as to fine mechanical detail, as to the materials used, and in accordance with the amputation level to which they are adapted. In choosing among these variations, the surgeon should work in liaison with the limb maker, for the one's knowledge of the condition of the patient and the peculiarities of the stump, not visible upon external inspection, will supplement the other's insight into the technical problems and difficulties involved. Between the two, the mechanical detail, the materials, and the need for special fitting can be determined to the best advantage of the patient.

In the first instance, the mechanical parts to be incorporated should be well adapted to the physical and mental capabilities of the amputee in order that the greatest efficiency may be obtained from them, and they should be as simple as possible and readily available within the locale, in order that construction and maintenance may be carried out at minimal cost and inconvenience.

As to the materials, not one but many are used in the construction of a single limb, some in the joints and harness, others in the foot, hand, or limb sections between the joints. They determine the weight, comfort, and durability of the prosthesis and their choice depends upon several factors. Primarily, each must have a high strength-weight ratio, must not change shape with time or use, and must be able to stand up under static, tensile, or compressive loads. In addition, all should be chosen with an eye to their suitability to climate and to the age, strength, and occupation of the amputee: the individual living in an extremely humid climate would not be satisfied with a limb which warped with dampness, the old or debilitated amputee would not wish a limb that was heavy and cumbersome, no matter how durable it might be, nor would the man working in the woods want a prosthesis which would dent and become misshapen if something were to strike hard against it. If the prosthesis is to be worn solely for the sake of cosmesis, that is yet another matter: in that event the lightness of weight and naturalness of appearance of the materials are of far greater importance than their durability. Availability is another factor which must be considered: if the limb must be sent away for replacement of parts or for servicing, the amputee will be put to considerable expense and will be inconvenienced by having to do without the limb for a time.

There are several materials which meet the above basic requirements and which have been found suitable in the construction of the segments of the limb which lie between the joints. Each has its own peculiar characteristics.

Wood. Wood is the most universally used. It is a substance which is very workable and therefore is easily formed and adjusted with a minimum of equipment and tools. The wooden limb may be hewn by hand from a solid block of linden, willow, or basswood, or it may be obtained from factory stock in a rough form and only the final contouring and fitting be done by the craftsman. Thus, it has the distinct advantages of being readily obtainable in either the large or the small fitting center, and of being easily adjusted to the idiosyncrasies of the individual stump. In addition, it has a good strength-weight ratio, permanence of shape, and, when covered with a proper shellac, has excellent sweat resistance and minimum friction. It has the disadvantage of being bulky

The walls of the shell formed of wood must be thick to give the desired strength, even though they are always reinforced with rawhide Consequently, though not heavy, the limb section is usually larger in size than the normal member Actually, in one respect, this very thickness is useful, for metal parts need not be placed on the outside of the shell but can be recessed within its walls Wooden limbs formed from *plywood* have been used successfully They must be molded about a plaster replica of the normal member, a process which requires special equipment and is therefore not practical in the small shop Except for this one factor, however, they possess all the advantages of the wooden limb and in addition have greater strength and are far less bulky

Metal The metal limb, in its usual form, is constructed of light aluminum alloy It has the advantage of light weight, high strength-weight ratio, and high resistance to compression and bending stresses Its disadvantages are that it lacks resilience and therefore becomes dented when struck a blow, that it is often noisy, requiring a sound-insulating material to be placed within the hollow shell, and that all steel parts, since they cannot be welded directly into the shell, must be riveted on the outside The manufacture of the metal limb requires a large amount of equipment and for this reason it is particularly adapted to mass production There are innumerable standard sizes and shapes, factory produced, and in the large fitting centers, where a large stock can be carried, the fitting of the individual and necessary repair can be readily accomplished Away from such centers the correct limb may not always be in stock, and servicing cannot be done because of the lack of equipment and parts The fact that the metal limb is light in weight and not cumbersome outweighs these disadvantages in many cases, and makes it particularly indicated for older individuals, especially if debilitated, for women, and for those who do not perform manual labor

Fiber Fiber is commonly used and is of about the same weight as wood, though slightly heavier than metal It possesses great strength (is generally stronger than wood without the excessive thickness), it is adaptable to mass production, but unlike metal is easily workable so that readjustment to the individual case is a simple matter However, it does have certain disadvantages It is less sightly because it must have overlapping seams, it is unfavorably influenced by extremes of humidity, becoming brittle when very dry, and tending to warp in excessive moisture, its construction is somewhat complicated in that it must be fitted with a leather socket for the reception of the stump, and that it must have incorporated in it a block of wood, metal, or plastic in which to set the joints

Plastic Plastics have recently been subjected to intensive study in the prosthetic field There are the natural plastics, such as shellac, and there are those which may be synthesized through the polymerization or chemical modification of natural substances It is the latter which are being used in the research on and production of artificial limbs They fall into two general classifications, the thermal plastics, and the thermal setting plastics The *thermal plastics* are permanently fusible They come in liquid form and may be poured into or painted on a mold, and then cured by heat to form a supple, nonrigid structure This tough, transparent, flame-resistant resin, when treated with proper plasticizers has proved very satisfactory in the construction of the cosmetic glove and has been used experimentally as a coating for limb segments to create a more lifelike appearance It is easily handled with a minimum of equipment and accepts pigment well, its chief drawback lies in the fact that the color of the pigment may be altered by the chlorine liberated during the heating

process if this step is not carried out with the utmost care The *thermal setting plastics* are permanently infusible and when cured, form a hard inflexible mass They are of two types. There are those which must be molded under pressure these require massive equipment and are suitable only for mass production, for this reason they are not practical in the construction of artificial limbs where individualization of shape and size and frequent adjustments are necessary However, there are also the thermal setting resins which can be painted on in liquid form and require no pressure but can be cured in a simple electric oven These substances are used to impregnate and bind together several layers of stockinet (nylon or cotton), rayon, or glass cloth, and, with the fabric to give structural strength, are proving excellent in the construction of sockets and limb segments These thermal setting plastic limbs have many valuable qualities they are easy to manufacture and may be designed for the individual by forming them over a plastic replica of the stump or of the normal limb, they retain their shape well, they hold hinges and appliances securely, they are strong, light, perspiration- and moisture-proof, and impervious to soap, water, or organic solvents, they apparently have no toxic effects and cause no allergic reaction when in contact with the skin It is my opinion that the plastics, when further investigated, will form the basis for a substantial advance in the field of materials to be utilized in prosthetic appliances

The following materials are used in the construction of joints and harness and as reinforcement and cushioning in the limb sections

Steel Steel is used principally in the structural framework and the joints of the artificial limb The three most suitable types are (1) stainless steel, (2) chromium-plated high carbon steel, and (3) chromium-plated alloyed steel There are several variations of these three types, and the one selected should be known to possess minimum weight, maximum strength, and easy workability by the limb maker

Leather· Leather finds its principal use in the construction of socket and harness It is easy to work with a minimum of tools but it does have certain disadvantages It develops an unpleasant odor due to the absorption of perspiration, it stretches under the influence of moisture, and, when used as a socket, it must be reinforced, which adds to the over-all weight of the limb

Rawhide Rawhide is another form of leather and is used extensively as a reinforcing agent for wooden limbs and feet

Rubber Rubber is most frequently used in the artificial finger tips to provide friction surfaces, in the ankle to form cushion bumpers, and on the bottom of the wooden foot to soften the load Certain artificial feet are made partially or wholly of rubber The most valuable type is pure gum rubber which possesses maximum spring and cushioning effect The synthetic rubbers have been found to lack resilience and elasticity and to degenerate with use

The final factor which influences the comfort and usefulness of the prosthesis is personalization of fitting and alignment An exact fit cannot be fully accomplished at once, but readjustments must be carried out over a period of time until each detail is as nearly perfect as possible Even then, routine limb checks should be made until shrinkage is complete and the stump has reached its final form Thereafter, periodic checks should be undergone, especially if there is discomfort, or if a new limb has been acquired

The following pages will be concerned with a survey of the prostheses at each amputation level with stress largely upon the peculiar fitting problems of each, the degree of functional replacement which may normally be expected, and

those points which should be closely observed during limb check Mechanical detail will be studied only in those instances where it materially affects the choice, the function, or the fit of the prosthesis

PROSTHESES FOR THE UPPER EXTREMITY

The upper extremity is one of the most important parts of the human body from both the cosmetic and the functional standpoint The loss or distortion of its structures creates a disfigurement which is a seriously disturbing factor in psychological adjustment, for it is a member which is much in evidence in most actions and social contacts, and is little disguised by clothing The loss or impairment of its function results in grave disability, for it is the hand, supported, guided, and activated by the arm, which performs most of the ordinary tasks of everyday life and the specialized tasks which contribute to the economic and social well-being of the individual The normal human hand is a part of amazing dexterity its bony structures and many articulations together with its neuromuscular elements make it capable of the fine movements which form the basic functions of grasp, pinch, and hook, and its highly sensitive integument affords an all-important sense of touch The normal human arm has a dual function it supports the hand, and its articulations and musculature accomplish the positioning of that member and the consummation of its functions, while, in itself, it provides the grosser movements of lifting, pushing, and pulling

Ideally the prostheses for this extremity, or portion of it, should be lifelike in appearance, should present the structures essential to perform the functions of the normal, and should substitute for the activating elements some mechanical means of consummating those functions This presents an engineering problem which is all but insurmountable Consider that the skin is mobile, sensitive, and individual in appearance, that each finger is capable of flexion, extension, and rotation, that the wrist passes through a complete range of circumduction, that the forearm is capable of pronation and supination as well as flexion and extension at the elbow, that the shoulder passes through the full range of circumduction, and that there is a vast number of neuromuscular elements which power and control these movements It is hardly to be expected that man might create such a structure and provide it with motivating power by harnessing the force of other body segments However, years of research, trial, and error have resulted in prostheses for this extremity which, though not comparable to the human hand and arm, provide a good functional substitute for them Unfortunately these truly functional prostheses are sadly lacking in one respect—they do not fulfill the demands of cosmesis, for in spite of intensive effort in the field of research, it has so far been impossible to combine in one device both utility and lifelike appearance For this reason, the upper extremity amputee must make a choice between the two In all but the occasional instance, he will prefer to sacrifice the semblance of normalcy for the sake of function It is the hope and endeavor of the artificial limb industry and the many active research groups that the gap between cosmesis and utility will some day be spanned, but until that time the amputee must adjust himself to the available

The functional hand devices commercially available at present are the split hook and the artificial hand Both are motivated in the standard prosthesis by a pull cord which passes along the side of the limb to the shoulder harness and thence across the back to loop about the opposite shoulder A forward motion of that shoulder or of the stump shortens the cord and thus transmits the activating power The cord may pass along either the radial or the ulnar side of the

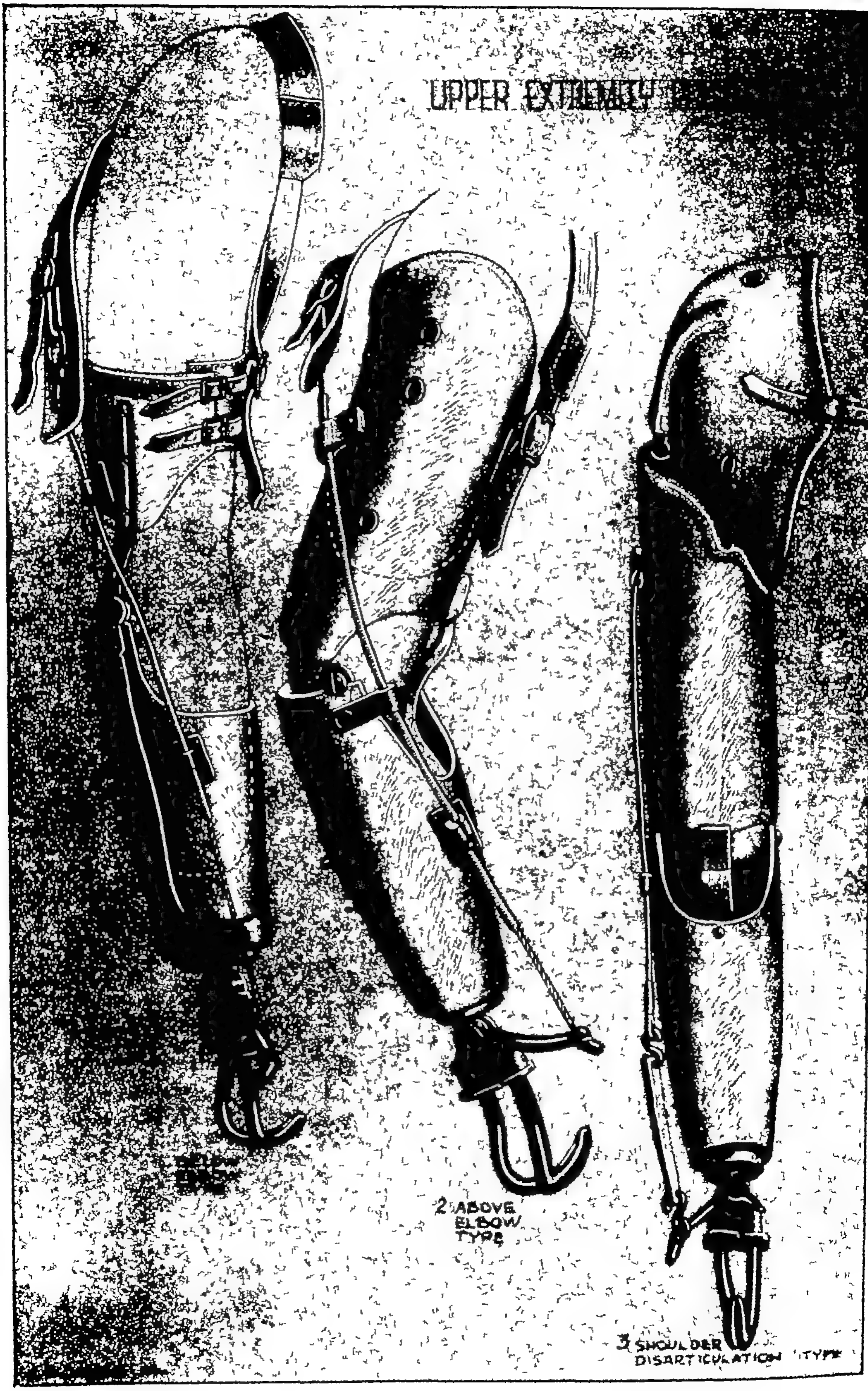

UPPER EXTREMITY
2 ABOVE ELBOW TYPE
3 SHOULDER DISARTICULATION TYPE

Fig. 318

arm prosthesis, depending upon the individual wish of the patient. In the first instance it is more efficient, but in the second it has a less restricting influence upon abduction.

Pull cords are made of catgut, leather, or the recently developed Bowden-type cable. With the first two there is considerable friction created as the cord passes through the leather loops which are used to hold it in the desired position. This is minimized in the Bowden cable for it is composed of supple metal strands which pass through a flexible housing of spring wire. The catgut and leather pull cords are attached to the hand device by an S-type hook, and the Bowden

THE HOOK

319 321

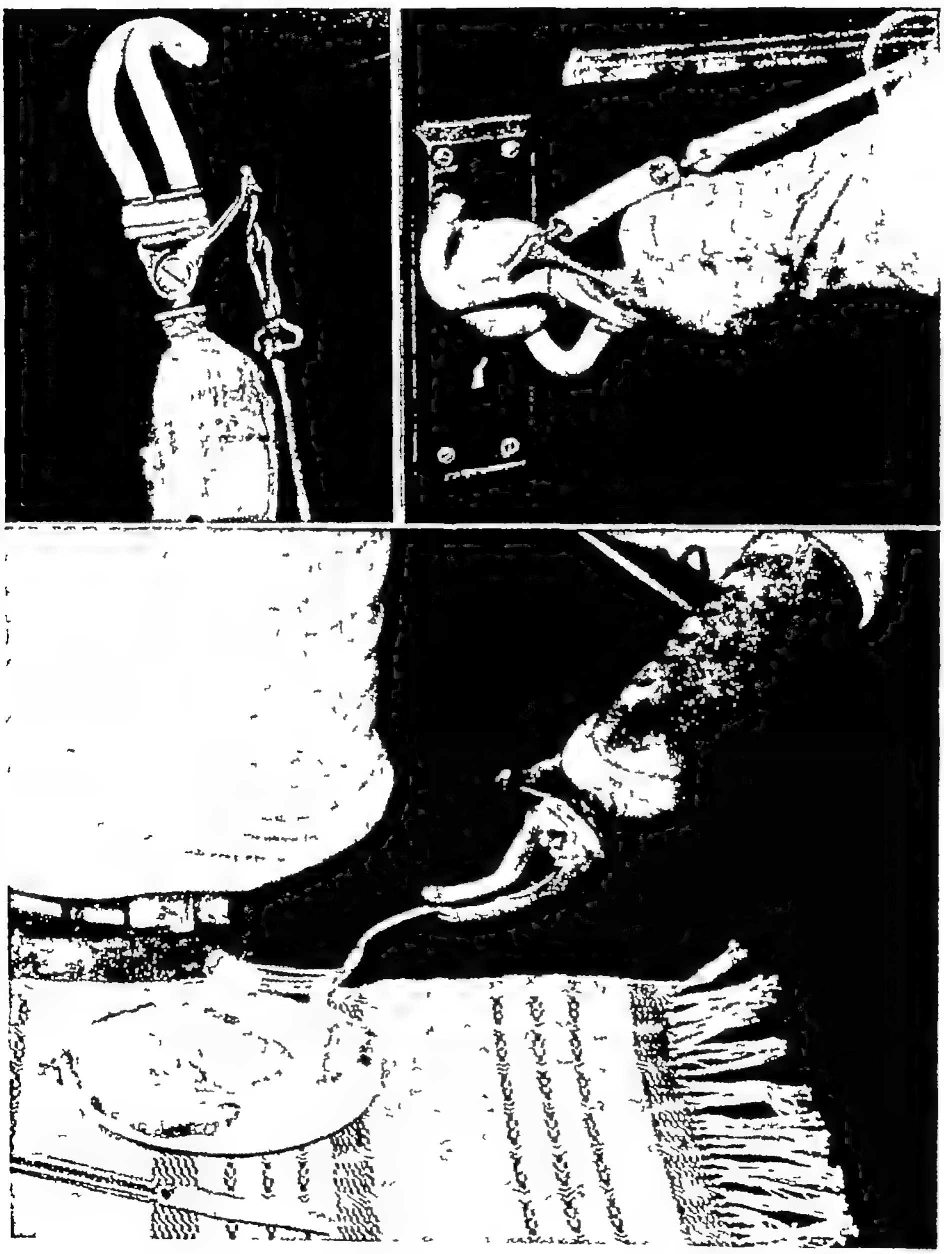


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Fig. 319.—The hook in the resting position with the two lever arms approximated by heavy rubber bands at their bases. (Walter Reed General Hospital Neg. No. 4281-3.)

Fig. 320.—The hook in use holding a small object. (Walter Reed General Hospital Neg. No. 4206 A3.)

Fig. 321.—The hook in use grasping a large object. (Walter Reed General Hospital Neg. No. 4206 A5.)

cable by a special quick-disconnecting mechanism which is adapted through the use of a ball bearing mounted on the end of the cable and fixed within a slot in the hand or hook. Various attempts have been made to transmit power from the leg, foot, abdomen and lower chest, but these have not proved practical because of the annoyance to the wearer of the excessive amount of cable and harness. Similarly, electrical systems, whether acting through motors or magnetic force, have never passed a research phase; they involve a network of wiring which is inconvenient to wear, they require the carrying and frequent recharging of batteries, in order to supply adequate power they must have an intricate gear mechanism which slows down the motion response to an undesirable degree. Hydraulic systems have much the same disadvantages, and at the present stage of development are not practical.

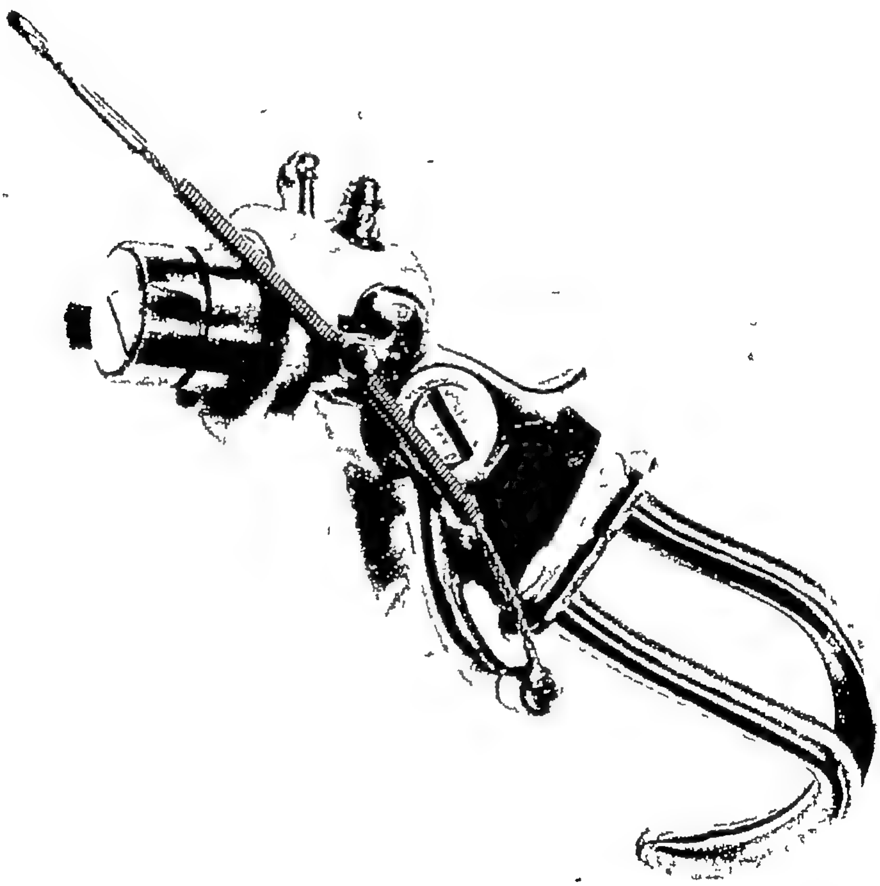


Fig 322.—The Turret hook. This special mounting for the Dorrance hook is designed for use in special cases, particularly bilateral amputees. The desired degree of flexion is manually set, at the hinge in the turret, while the desired degree of rotation is fixed (also manually) at the wrist connection in the frame of the forearm piece. (*Courtesy A. J. Hosmer Corp.*)

The utility **hook** is by far the most practical work appliance yet devised for the upper extremity. It consists of an adapter which fits within the end of the artificial arm and two metal pieces in the general shape of a hook. One of these pieces is a rigid extension of the adapter and acts as a fixed pole, the other is hinged to the base of the first and acts as a movable arm. From this movable piece extends a side arm to which the cord is attached. About the two units are placed strong rubber bands under tension. As the cord is shortened the side arm is drawn upward pulling the movable arm away from the fixed piece and opening the hook; as it is lengthened the tension of the rubber bands about the two

arms pulls them together, closing the hook in pincerlike action The strength of the grip exerted by the hook is dependent upon the number and tension of the rubber bands In place of the adaptive mechanism of the hook, there may be mounted into the forearm piece individual fittings for work tools, or a single chuck which will hold any one of a variety of tools Some recently developed improvements in the hook are decreased weight, application of power through the centrum of the hook, and a new type of adapter mechanism consisting of a double cam actuated brake released by a simple push button This last allows for rotation of the hook or work unit and makes its mounting and removal a quick and easy process

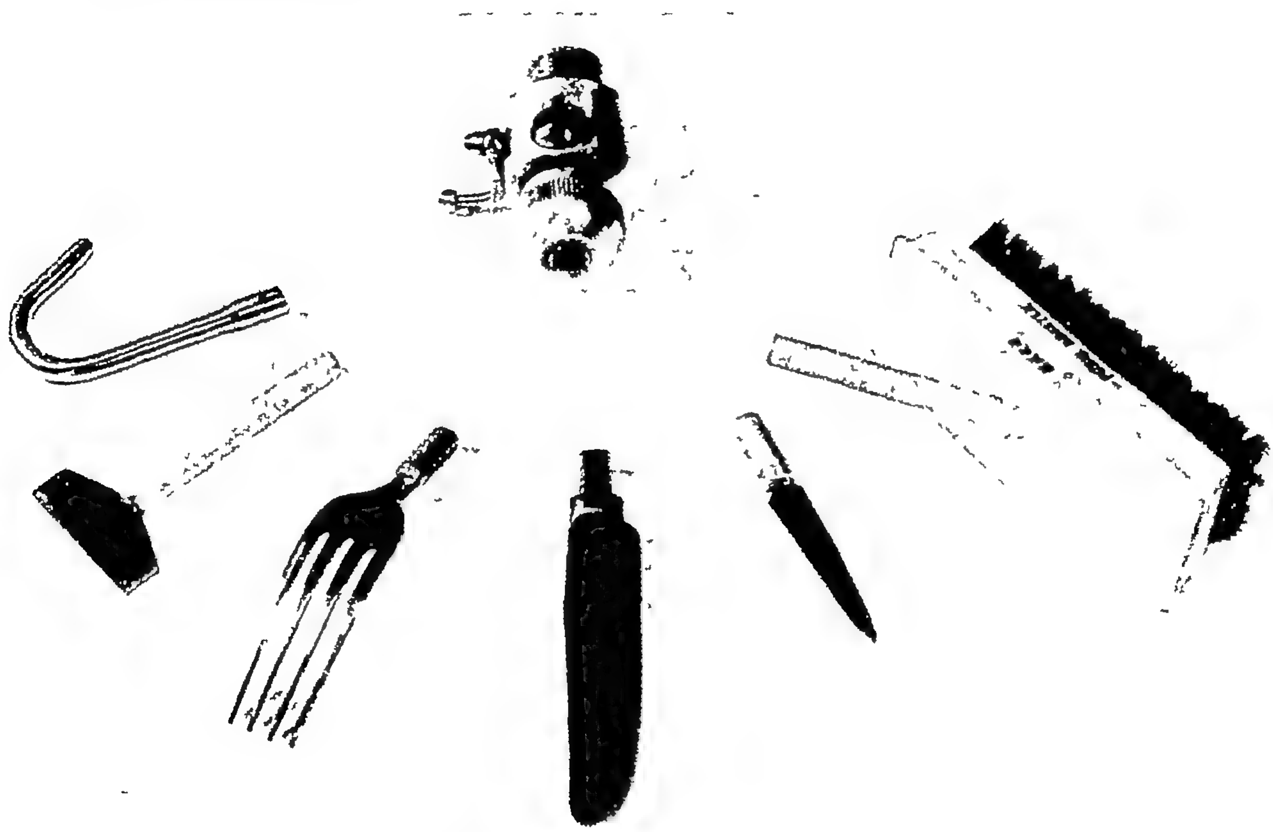


Fig 323 —Tool holder and accessories This tool-holding device consists of a simple collet chuck, hinged at its base to the wrist adapter, for varying degrees of flexion It is stabilized at the desired point by a manually operated lever Rotation is fixed at the desired point at the wrist connection Any article which can be fixed within the chuck can be adapted to it (Courtesy A J Hosmer Corp)

The **artificial hand** may be constructed of wood, metal, or plastic It simulates the normal hand in shape and contour and may be camouflaged by a leather or cosmetic glove For this reason it is a more sightly member than the split hook, but as a functional tool it is far less efficient There are two general types of artificial hands most commonly used these are similar in that they both adopt the basic principle of *flexion* and *extension* of the fingers at the metacarpophalangeal joints, they differ in the manner in which the activating power is applied In one the fingers rest in the closed position with the index finger in apposition to the thumb, and the pull of the cord causes them to open so that an object may be placed within them, spring action upon release of the force allows them to close about the object and grasp it firmly Usually in this type the ring and little fingers are in a semi-

flexed position and they and the thumb are stationary, while the middle and index fingers are slightly curled and flex and extend as one unit In the other type the fingers lie in the open position and the pull cord causes them to close about an object, usually there is a rachet mechanism which functions when a small lever is pressed by the normal hand, and which holds the hand in the desired amount of closure until the lever is again switched, spring action, when the power is released, brings the fingers again to the open position In this hand there is considerable variation generally, the thumb and the four fingers flex at the metacarpophalangeal joints, the fingers all curling slightly and moving as a single unit, in some, both index and middle fingers appose the thumb, in yet others the ring and little fingers are fixed with only the index and middle fingers and the thumb flexing, and in a few the ring and little

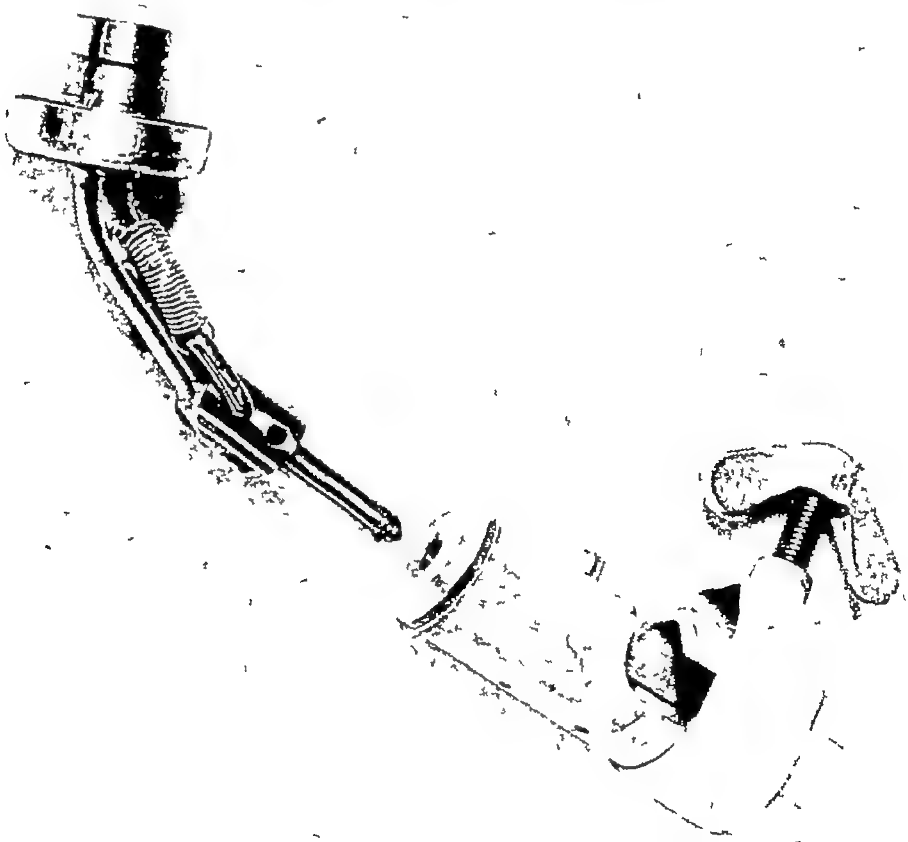


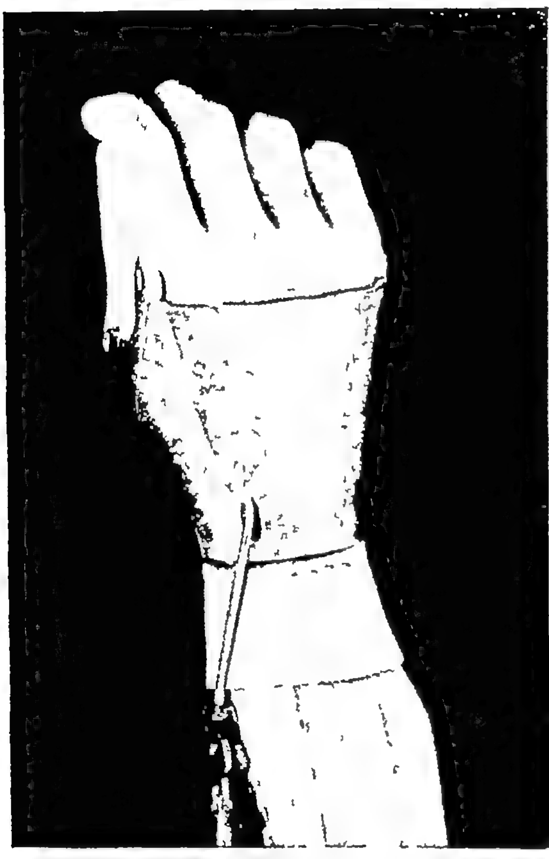
Fig 324—A farm utility tool This special adapter is designed to hold various farm tools to the artificial arm and provide universal motion near the wrist level A button on the upper surface of the holder releases the tool from the prosthesis The shaft end, which inserts into the holder, can in itself be used as a fixed position hook, for such activities as carrying a pail, by simply tipping it upward into a flexed position where it is stabilized by the mechanism (Courtesy A J Hosmer Corp)

fingers move as a single unit separate from the other fingers Both of these models are heavier than the normal hand (usually weighing one and one-half pounds), and are far more bulky Neither of them possesses flexion and extension of the interphalangeal joints, or provides rotation of fingers and thumb Their size and this lack of finer movement makes them awkward in everyday use and useless in delicate work There are, however, current improvements not yet commercially available which should reduce these disadvantages They are a hand with greater contact surface between the apposed thumb and fingers, a

thumb which may be placed in several positions to ensure better contact and greater use, fingers which will curl about an object, new lightweight materials for construction, power boosters, inside controls passing through the center of the limb rather than outside of it, and hydraulic and electrical actuation units Research scientists hold high hopes that these and future developments may result in an artificial hand which approximates the weight and size and which is capable of the majority of the fine movements of the normal hand Such a mechanical hand, covered by a perfected cosmetic glove of lifelike appearance, would resolve the problem of function versus cosmesis

The existing hand devices contrived for appearance alone are the cosmetic glove and the cosmetic hand

THE ARTIFICIAL HAND



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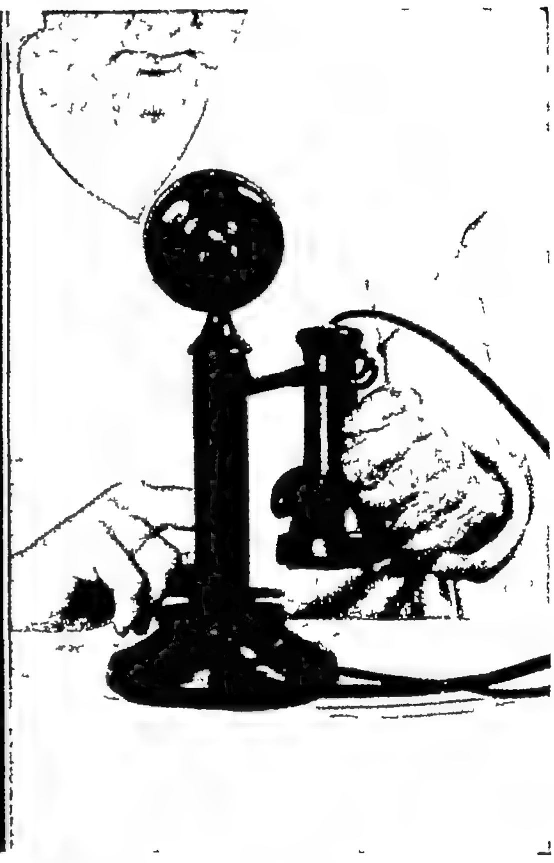

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Fig 325—An artificial hand (Walter Reed General Hospital Neg No 4333-1)
Fig 326—An artificial hand in use (Walter Reed General Hospital Neg No 4308 4)

The **cosmetic glove** is a lifelike covering worn over the artificial hand, or over the hand which is partially amputated In the latter instance it does not represent a complete hand but only those elements which have been lost there being apertures within it through which the remaining normal digits protrude This design gives the hand a fairly normal appearance and still affords the use of the existing parts The basic requirements of such a glove are

1 It must be very lightweight

2 It must be lifelike in appearance it should contain the normal skin creases and folds in minute detail including the whorls of the fingers it must have the normal contours of the hand, including the effects of veining, it must

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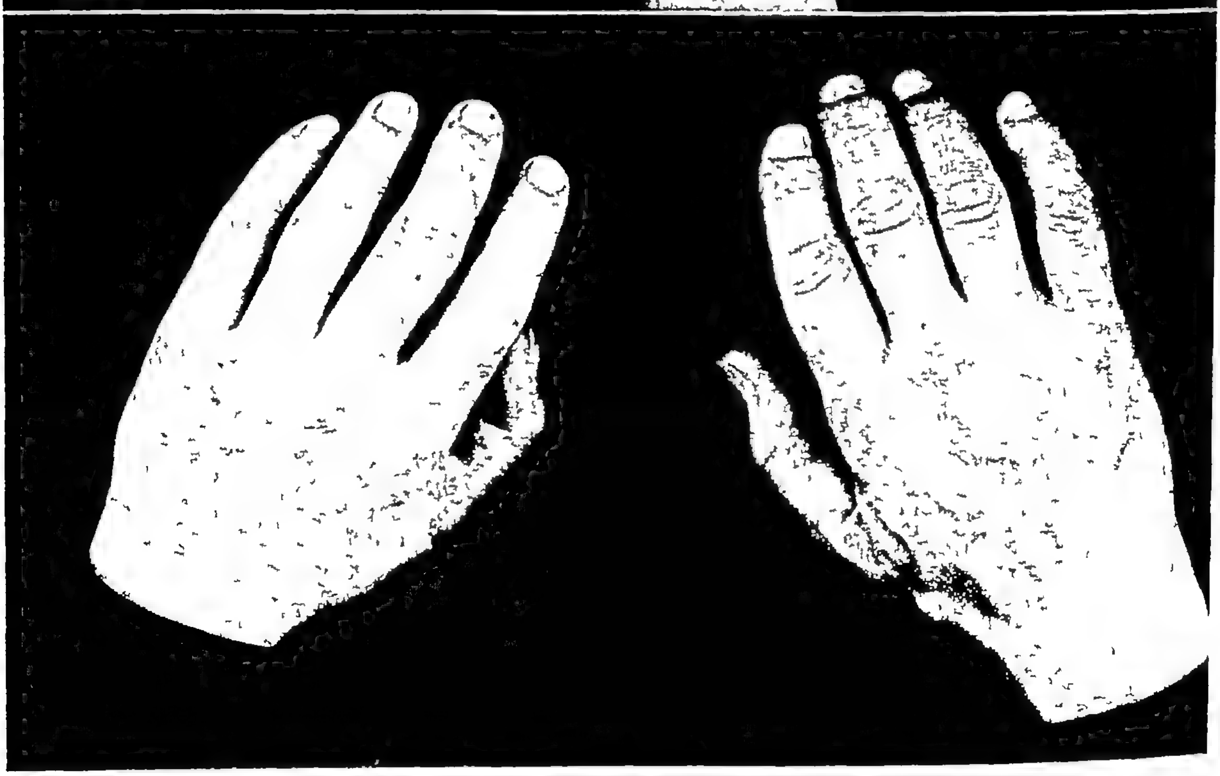

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Fig 327—Partial amputation of the hand with but the thumb remaining, showing stump, prosthesis, and normal hand (Courtesy Prosthetic Services, San Francisco)

Fig 328—Same case, showing normal and cosmetic hands (Courtesy Prosthetic Services, San Francisco)

Fig 329—Amputation of all fingers and thumb, showing normal hand, cosmetic glove, and stump (Courtesy Prosthetic Services, San Francisco)

330 331

Fig 330—Phalangized hand following amputation at the level of the metacarpal phalangeal joints (Courtesy Dr R H Alldredge England General Hospital Neg No SA 485)

Fig 331—Same case showing rubber cosmetic hand in comparison with the normal (Courtesy Dr R H Alldredge England General Hospital Neg No Sa 747)

have fingernails, flash lines and seams must be well disguised, it must be so colored as to present the normal pigmentation about the knuckles, fingers, and veins

3 The color must be permanent so that use and age do not result in fading and discoloration

4 The material must be tough, strong, and resistant to abrasion

5 It must be unaffected by soap and water so that it may be easily cleaned

6 It must be unaffected by fats, oils, and common solvents in order that contact with these substances will not cause surface deterioration leakage, or alteration of color

7 The material should be free from defects such as minute holes, bubbles, etc, and should be of uniform thickness

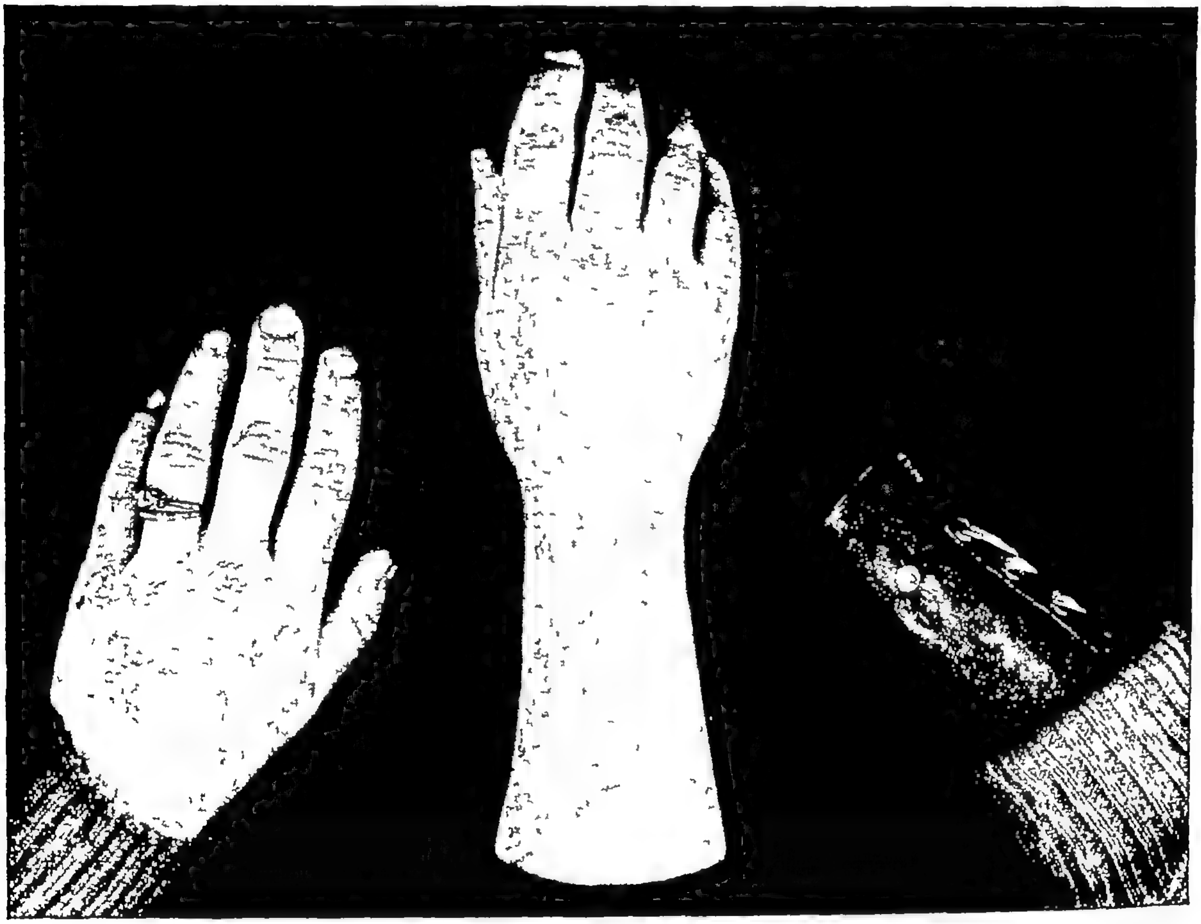

Fig 332—Cosmetic prosthesis for forearm amputations (Courtesy Prosthetic Services, San Francisco)

8 It should not distort under normal working conditions nor be subject to "cold flow"

9 The surface should not be slick but should present a moderate friction, sufficient to hold objects, without being "tacky"

Cosmetic gloves were first made of rubber They were very lifelike when new, but soon took on a "dead" appearance Sunlight and use affected them deleteriously, and cosmetics frequently had to be used to maintain their appearance Because of these disadvantages numerous other materials were studied, with the result that vinyl chloride, a plastic, was selected It appears to be the best substance currently available for this use as it most nearly meets all the

above requirements It must be carefully plasticized and treated with the greatest respect during the heating-molding process in order that the pigments used for coloring may not be altered by the liberated chlorine A glove fashioned from vinyl chloride weighs approximately two ounces

The purely **cosmetic hand** is just what its name implies, an object completely without function, fashioned to look like the human hand, and affixed to the distal end of the forearm It serves but one purpose, that is to fulfill the need or the desire for normal appearance This hand may be specifically indicated as an occupational necessity for individuals such as entertainers or it may be desirable as an adjunct to psychotherapy in some instances But in the main it is not a prosthesis which is generally used Occasionally, for purposes of morale it will be selected as the first hand to be worn but as the amputee becomes adjusted it is invariably discarded for the more functional type If, for some reason, a hook or an artificial hand cannot be used, the patient will usually prefer the empty coat sleeve

With the exception of the hand prosthesis, the upper extremity limb is relatively simple It is a shell which replaces length and supports a substitute for the hand, it contains no mechanical replacement for the elements of the normal arm which activate the hand, for power is furnished by the pull cord, but, if amputation has been performed above the elbow joint, it must be constructed with an artificial joint so that flexion and extension of the forearm can be carried out and the hand positioned It is made as light as it possibly can be and still remain durable An exceptionally light "dress arm" can be obtained for use with the cosmetic hand only

In fitting the upper extremity limb it should be borne in mind that the stump acts only as a lever for control of the prosthesis and is not used to bear weight, seldom receiving any upward pressure It should, therefore, fit snugly in the socket so that it will not tilt within it and receive pressure upon the terminal suture line

Prostheses for Amputation of the Fingers or Thumb

A functional prosthesis is neither necessary nor practical for the hand upon which sufficient digits remain to consummate grasp and pinch, but a cosmetic prosthesis may be employed if a camouflage of the deformity is necessary for occupational or psychological reasons A single finger may be replaced by a natural-appearing extension of plastic or latex, which is slipped over the finger stump and maintained there by suction after the air is forced from it by insertion of the finger remnant When no stump remains, or when more than one finger is to be replaced, a cosmetic glove of the type described previously with apertures for the placement of existing digits may be worn This extends above the cuff line for the sake of disguise and can be very lifelike in appearance However, it restricts the free use of the hand and covers large areas of the skin thus detracting from its sensory function and resulting in discomfort from perspiration

A hand which has suffered partial amputation and in which the loss is such that no amount of reconstruction surgery can make of it a functional tool is a different story In that event a working prosthesis may be practical and most advantageous Such a hand is one from which all of the fingers or the thumb have been severed above the web space It lacks a pole against which the remaining digit or digits can consummate the basic functions of grasp and pinch The purpose of the prosthesis is to substitute for that pole and it consists of a cuff which fits about the hand with a post extending from its distal end in such a

position that the remaining digit or digits can readily appose it This device is constructed of molded leather reinforced with steel It is restricting, making circumduction of the wrist almost impossible, confines the hand stump so that it cannot be used in hook and push action, and, like the glove noted above, nullifies sensation

WORK PROSTHESES FOR PARTIAL HAND AMPUTATION

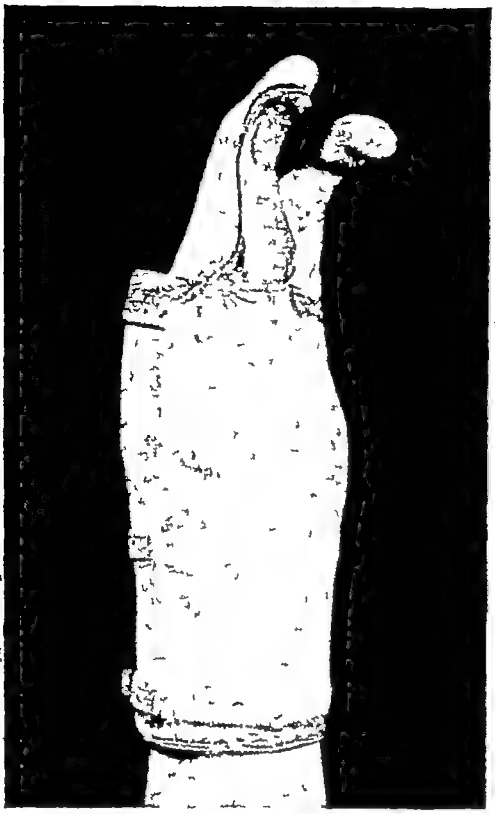

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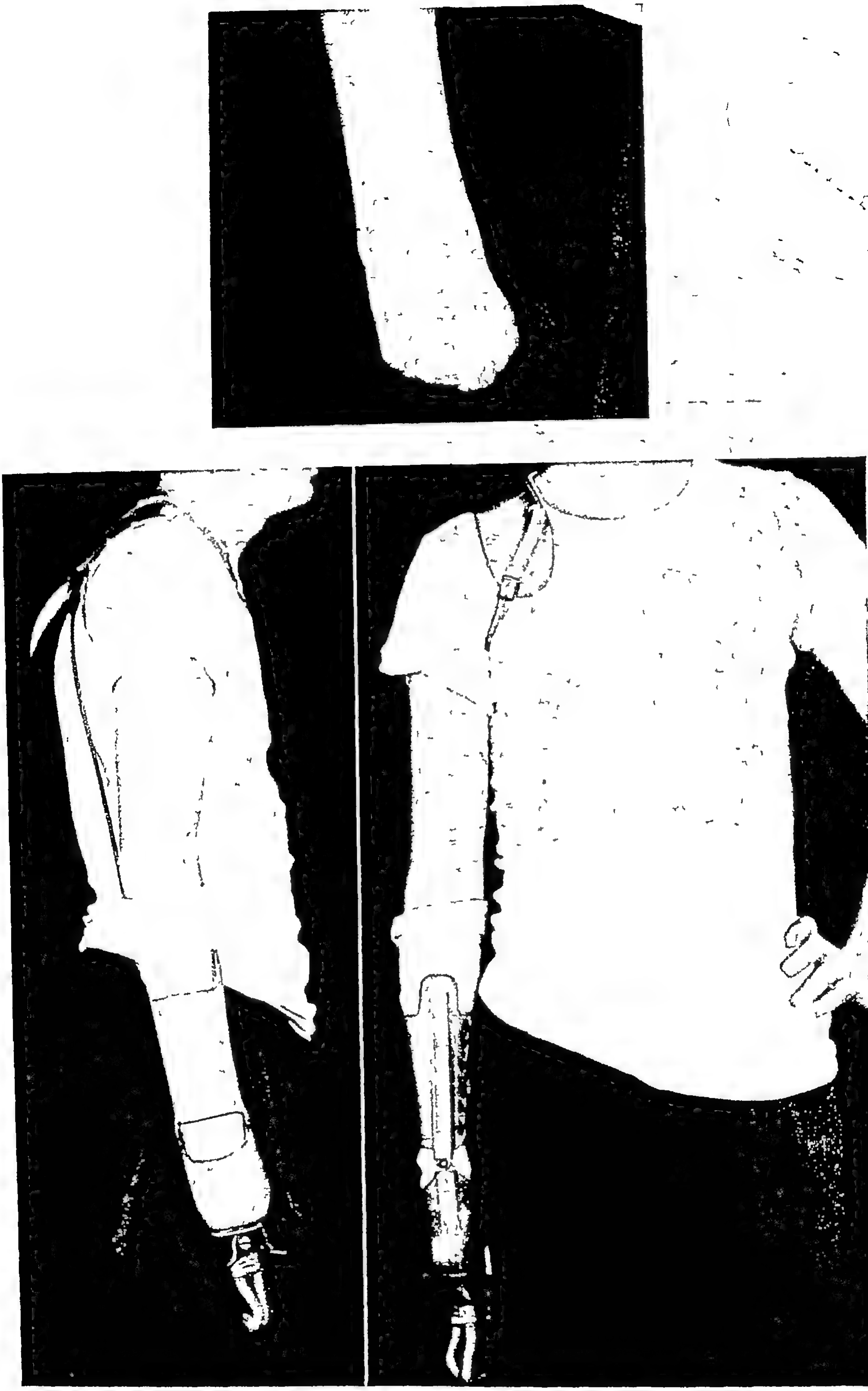
Fig 333 —Prosthesis for amputation of thumb, index, and little fingers The leather covered steel thumb piece is riveted to a molded leather cuff which is fitted to the stump with straps and buckles (Walter Reed General Hospital Neg No 4349 3)

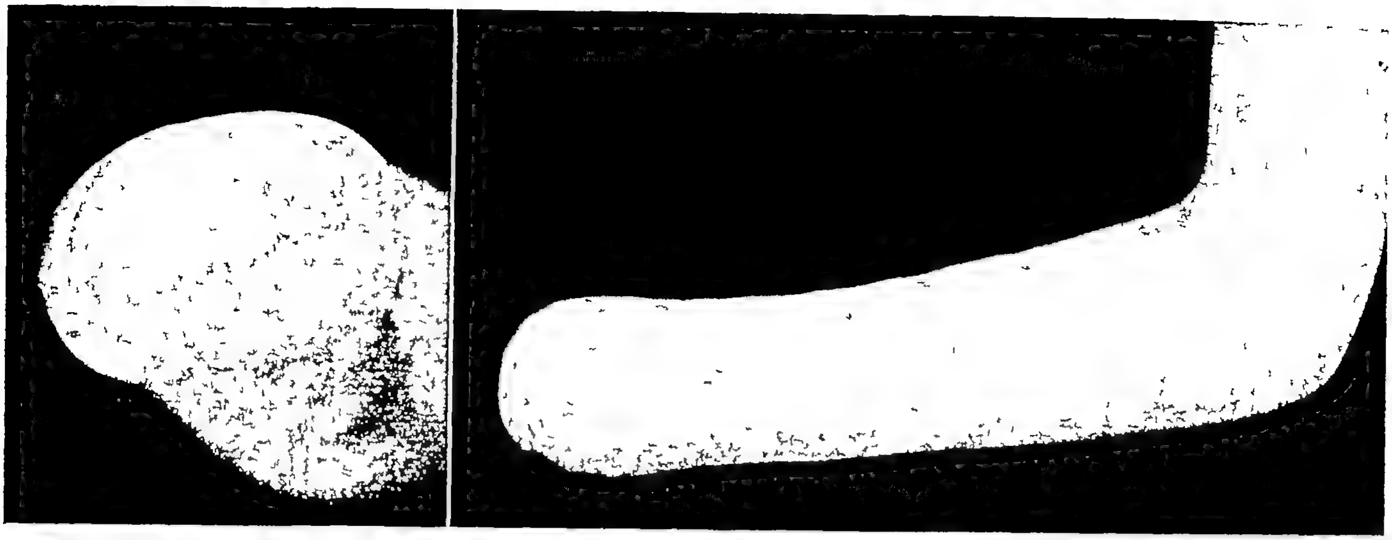
Fig 334 —Prosthesis for amputation of all fingers with the thumb remaining (Bushnell General Hospital Neg No 8380)

Prostheses for Amputations About the Wrist

When amputation occurs about the upper part of the metacarpus or through the distal carpus, the functions of grasp and pinch are lost, but the stump retains flexion and extension of the wrist and pronation and supination of the forearm It is still highly useful in holding and pushing objects and in hook action where the bent wrist can substitute for the fingers For this reason a prosthesis may not always be desired, though it is well, if the stump is nontender and well formed, to use it both with and without for a trial period The aim of an artificial limb at this level is to provide pinch and grasp without interfering with the wrist action or the pronation and supination of the forearm The standard prosthesis consists of a molded socket for reception of the metacarpus or distal carpus, a leather cuff about the forearm, and a steel frame which joins and reinforces the two and contains at its distal end the mounting for hook or artificial hand The cuff extends only to the junction



Figs 335-337.—Trans-metacarpal amputation and prosthesis Note the excessive length of the prosthesis, the joint for flexion and extension of the wrist and the fact that the elbow joint is free from restrictive harness (Walter Reed General Hospital Neg No 4463 1,4 5)



Figs 338 and 339—The stump (Walter Reed General Hospital Neg No 4281 1,2)

Figs 340 and 341—The prosthesis, showing the range of pronation and supination, the height to which the prosthesis reaches on the stump, the freedom of the elbow from restrictive harness, and the use of the hook (which is interchangeable with an artificial hand) (Walter Reed General Hospital Neg No 4206 A1, A2)

of the middle and upper thirds of the forearm, thus eliminating the necessity of an artificial elbow joint which would have a restricting effect upon pronation and supination, the steel frame is articulated at the level of the wrist in order that the flexion and extension of that joint may be preserved The principal disadvantage of this prosthesis is the excessive over-all length of the artificial arm as compared to the normal arm The cosmetic glove for this level simulates a complete hand and simply slips over the stump end far enough to be secured without additional retentive apparatus

Prostheses for Disarticulation of the Wrist

A special prosthesis has been designed for disarticulation of the wrist or through the proximal carpal row It consists of a molded socket which extends from the stump end to the junction of the middle and upper thirds of the forearm (it should not go higher than this point lest it limit pronation and supination), to which is fixed a U-shaped steel band which passes over the distal end of the prosthesis from the anterior to the posterior side and upon which is mounted a receptacle for attachment of the artificial hand or hook A cuff is usually required about the shoulder for the pull cord to pass through in order to keep it from bowstringing across the axilla Either leather or plastic may be used in the construction of the socket When leather is employed the radial split is laced firmly together with a leather thong, when plastic is used it is closed by a piece of elastic webbing The plastic is neater in appearance but is somewhat difficult for small shop construction Although this prosthesis does not provide flexion and extension of the wrist, it does preserve pronation and supination, for the socket grasps the broad flare of the radial metaphysis firmly and obviates the necessity of an upper arm cuff and a restricting artificial elbow joint This prosthesis is a worth-while functional unit if applied over a stump that is painless and covered by satisfactory palmar skin, and should always be employed at this level in preference to the forearm prosthesis which would extend well beyond the length of the normal hand and arm, would lack pronation and supination, and would require harness above the elbow. This last factor, freedom from harness, is of far greater worth to the amputee than mechanical analysis would reveal

Prostheses for Forearm Amputations

The ideal level for amputation of the forearm is at the junction of the middle and lower thirds, or two and one-half to three inches above the wrist joint From the prosthetic standpoint this is the most satisfactory amputation in the upper extremity for it is the most easily fitted With a stump of such length there is room for the frame of the prosthesis to taper smoothly to the normal size of the wrist with no undue bulk, and the wrist connection element can be of the standard type requiring no special molding or shaping

It is for the stump of ideal length that the standard forearm limb has been designed It has as its basic structure a "U-shaped" metal frame which extends from the level of the wrist to the upper arm and is articulated for elbow motion To its distal end is mounted the hook or hand within its distal portion lies the socket for reception of the stump and to its proximal flanges is fixed a cuff which encircles the upper arm and serves to hold the limb to the body and stabilize it against rotation The elbow articulation is placed at the level of the humeral epicondyles and is activated by the stump itself When the simple single hinge is employed, the arc of rotation of the prosthesis is slightly less than that of the normal arm when two hinges are used in series a wider more comfortable

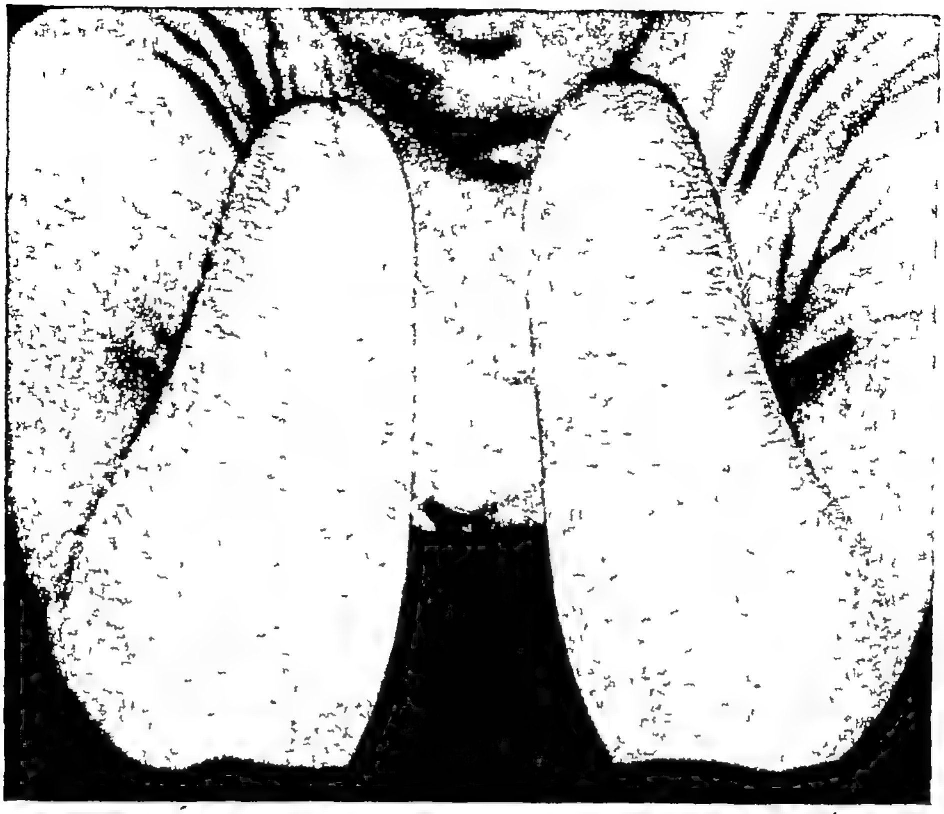


Fig 342—Ideal forearm stumps (Walter Reed General Hospital Neg No 4593 1)

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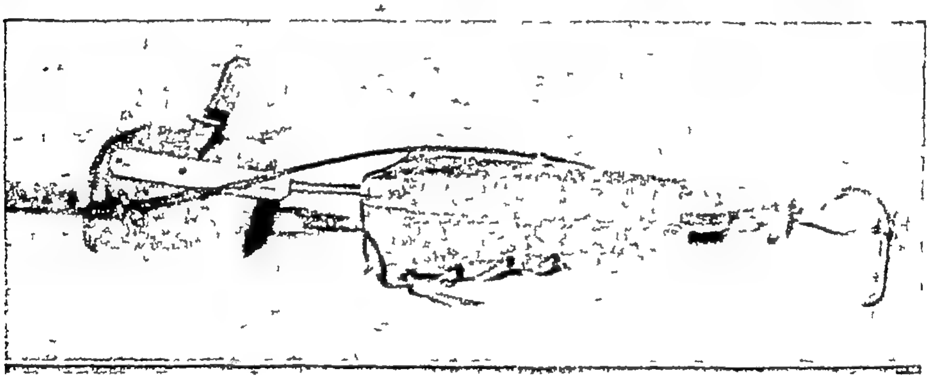

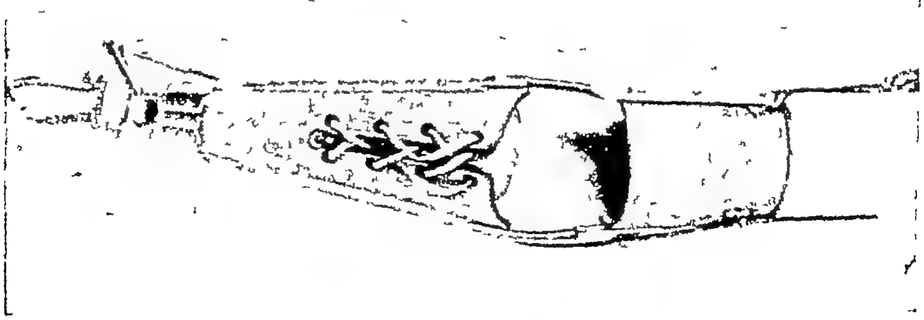

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Figs 343 and 344—Standard forearm prosthesis with special elbow joint (This is not adaptable to a short stump) In side view, note frame, socket, hook, upper arm cuff, and spring and cable substitute for elbow hinges In back view, note lacing for adjustment of socket For standard elbow hinges see Figs 357 and 358

range of motion, particularly in extreme flexion and extension, is provided A stop is present in the joint at 180 degrees to prevent hyperextension The socket of the prosthesis extends well up on the forearm It should be molded carefully to ensure against undue motion of the stump within it and to allow enough clearance between it and the elbow so that its rim will not impinge upon the front of the elbow in the course of flexion The material used for its construction may be leather, wood, or plastic leather has been most popular because it is handled with ease, wood is not generally used because it forms a thick and bulky

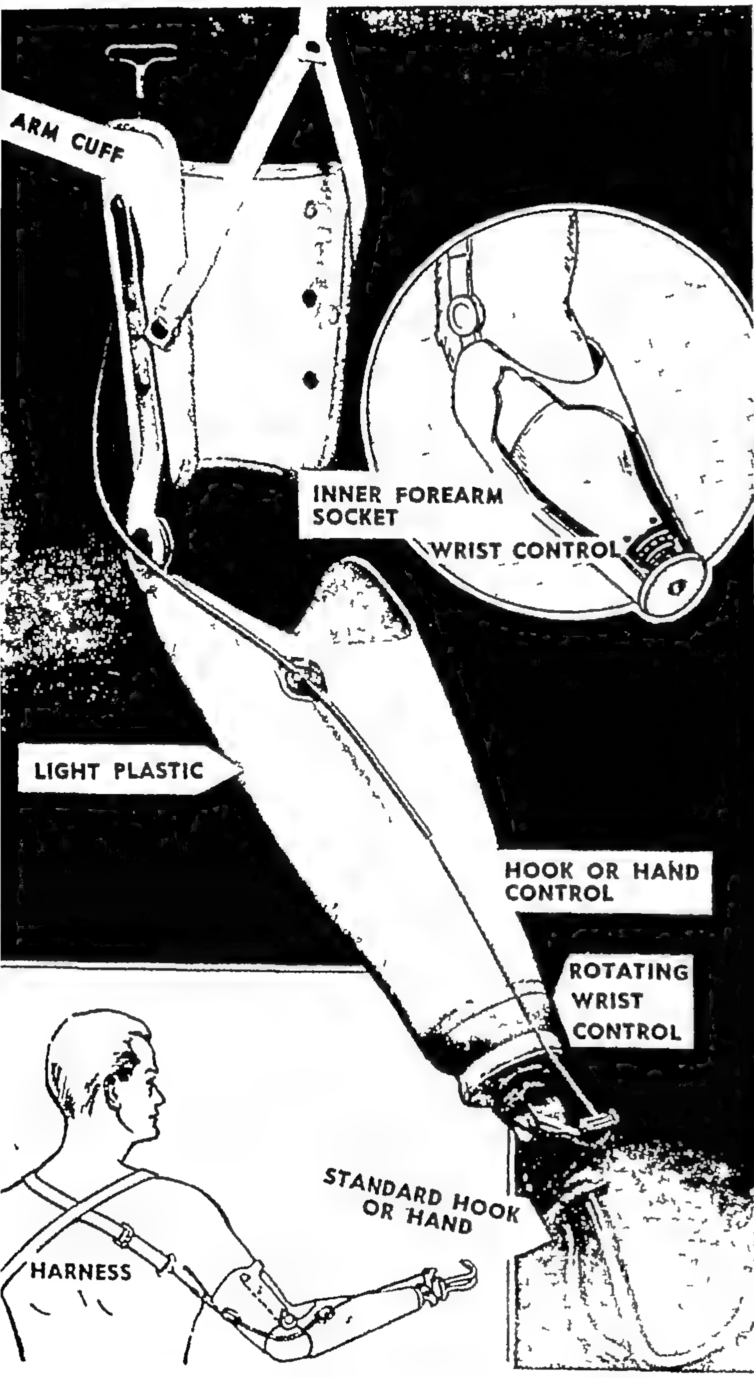

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Fig 345 —The Northrop below elbow arm The cutaway diagram shows the method of applying forearm rotation to the hook or hand, and the clutch arrangement which locks the hook or hand against rotation impelled by outside force (Courtesy Veterans Administration)

Fig 346 —Posterior view of Northrop arm showing the inner socket which receives the stump (Courtesy Veterans Administration)

shell, plastic has not been extensively used to date because it is a recent development and cannot be readily handled in the small shop, but it makes a socket which is light, clean, and neat in appearance

Differing radically from the standard prosthesis in fundamental design is the Northrop arm, now entering production stages after several years of experimental work It has no steel framework but is composed of two plastic shells The forearm piece has embedded in its distal end a rotating wrist mechanism which is attached to the socket which lies within the shell, the upper arm piece is a half shell which fits across the back side of the arm and tapers upward approximately to the insertion of the deltoid muscle The two pieces are joined by an elbow hinge incorporated directly in the plastic, and the whole is fixed to the arm by a leather cuff fastened to the upper shell and strapped about the upper arm The principal feature of this device is the rotating wrist mechanism, powered by the stump fitted within the socket, which affords pronation and supination even in the presence of an elbow joint This mechanism is so designed that the rotation of the hook or hand is in a ratio of 2 3 to 1 of the stump itself It is equipped with a lock which prevents an outside propulsion from

A PROSTHESIS FOR THE LONG FOREARM STUMP

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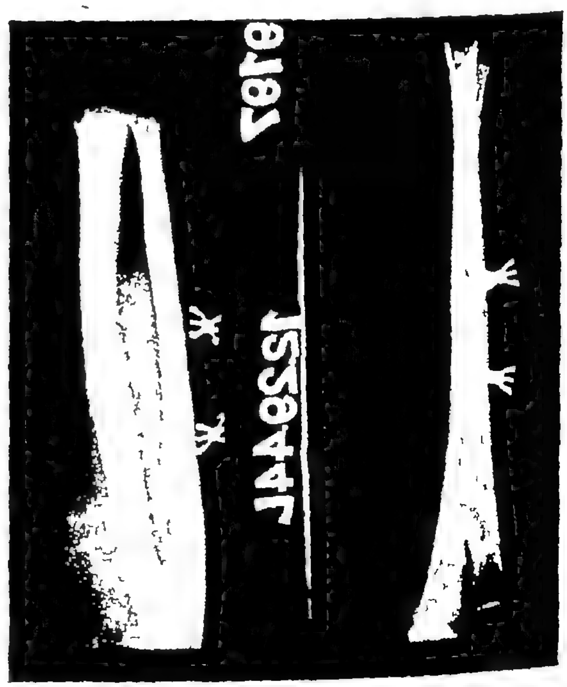

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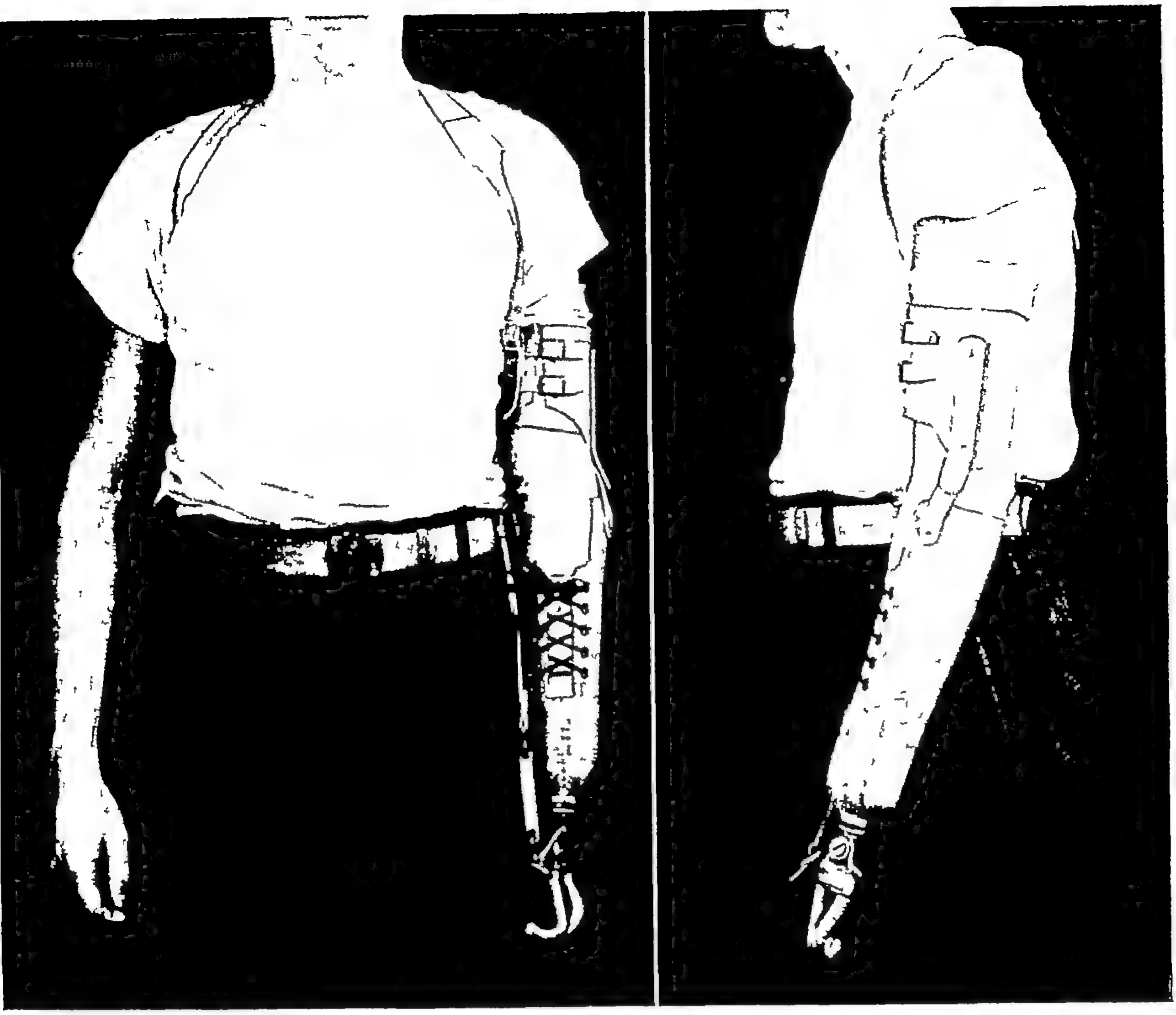
Figs 347 and 348—The stump, and x rays showing bone level (Walter Reed General Hospital Neg No 4260 2, 4274 A)



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Figs 349 and 350—The prosthesis In the front view, note that a molded leather cuff with special steel frame is used in place of the usual frame for forearm stumps to avoid excessive bulk, and that the length of the limb is slightly greater than that of the normal extremity even with a short hook In the side view, note the substitution of leather straps for the usual hinges (see Figs 357 and 358) which attach the forearm piece to the upper cuff This allows additional freedom of the arm through rotation (Walter Reed General Hospital Neg No 4260-1,4)

rotating the stump This limb is lightweight, clean, has no external framework to injure the clothing, and has the obvious advantage of providing pronation and supination

When amputation is performed through the lower third of the forearm above the level of the radiocarpal joint, the prosthesis is far more difficult to fit and is less satisfactory in appearance The socket must necessarily extend to or beyond the level of the wrist in order to accommodate the long stump, and the result is a limb which is bulky in that region and of greater over-all length than the normal extremity

When amputation is carried out above the ideal level in the forearm, a short stump remains The socket of the prosthesis must extend high on the forearm in order to grasp it, and this brings its upper rim against the antecubital space when the arm is flexed This situation makes fitting difficult and seriously impedes function, for these tissues press against the socket in its upward thrust,

causing it to slip off the short stump, and they act as an obstacle to flexion, limiting it to approximately 90 degrees In the fleshy individual these difficulties are even more pronounced In planning the socket for such a stump the limb maker first measures from the radial insertion of the biceps humerus muscle to the end of the stump and thus determines the amount of stump which can be placed within the socket If that length is sufficient, the amputee can be fitted with the standard forearm prosthesis with the use of a specially constructed socket and an additional leather strap passed around the arm just above the elbow to help maintain the stump in position Utmost care must be taken in

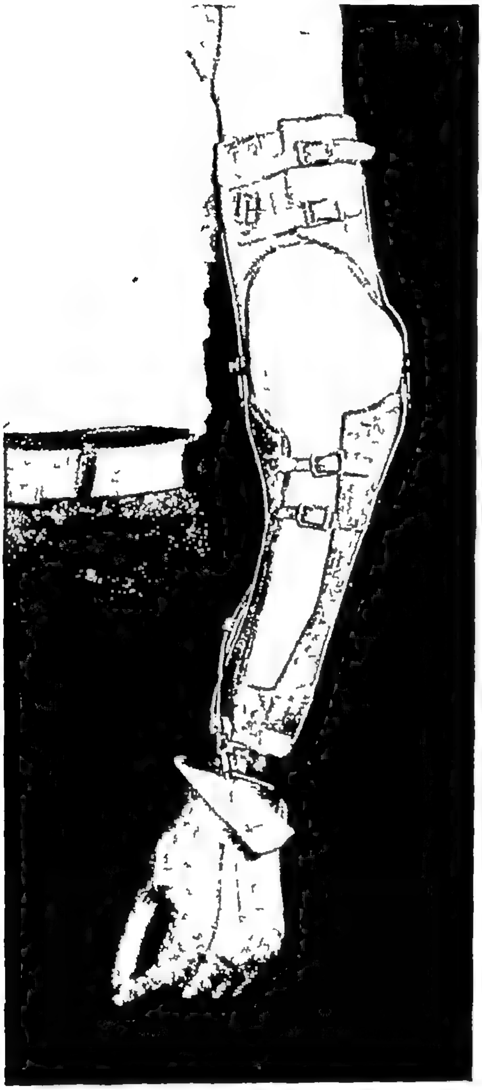


Fig 351—Prosthesis for amputation through the lower third of the forearm with malunited fracture of the radius and ulna Here the standard prosthesis is used with the usual steel frame, elbow hinges, and upper arm cuff, but a special molded leather cuff, open on the radial aspect, is used to admit the stump (Walter Reed General Hospital Neg No 4917-2)

fitting such a case If the stump is found to be excessively short, if strength in the prosthesis is not specifically required by the individual, or if the opposite arm is lost so that complete flexion is necessary in order that the amputee can feed himself and take care of his personal hygiene, a special forearm limb may be used which differs radically from the conventional in design but is based on sound engineering principles and has proved practical It is constructed with

the forearm piece in two sections a molded socket which lies within a U-shaped metal frame and which fits the length of the stump, and a forearm shell, fixed within medial and lateral metal shafts, which extends from the distal end of the socket to the length of the normal arm and to which may be attached either hook or hand Both are controlled by a special motion-multiplying hinge which makes the arc of motion of the prosthetic hand or hook two and one-half times that of the amputation stump, thus, for every 10 degrees of flexion of the stump, the hand will pass through 25 degrees This makes it possible for the amputee to perform many tasks such as feeding himself, combing his hair, etc, and since only limited flexion is attempted by the stump itself, there is far less tendency for it to slip from the socket This would seem to be the solution to the problems of the short below-elbow stump, but it does have one great drawback—it does not provide normal power, which is a tremendous disadvantage to the amputee whose occupation demands a strong working arm If strength is an important factor, the standard forearm prosthesis with special socket and strap above the elbow should be used

Prostheses for the Upper Arm

The standard upper arm prosthesis is composed of the artificial hand or hook, the forearm piece, the elbow block, the socket or upper arm piece, and the harness The hook or hand is of the conventional type and is fitted into a slot at the end of the forearm piece The forearm piece itself is a light, hollow shell with its upper end cut low on the anterior side to afford free play of the elbow joint during flexion, it is fixed to the elbow block by means of a bolt, the attachments of which are buried within the walls of the shell for cosmetic reasons The elbow block is incorporated directly into the upper arm piece and usually occupies about two inches longitudinally It contains a mechanism which allows the joint either to swing freely or to be locked at any one of several intervals between 180 degrees extension and 45 degrees flexion, the control for this mechanism is generally placed on the back of the forearm piece at the junction of the middle and upper thirds where it can be manipulated by the normal hand A strap of strong elastic webbing is placed across the front of the elbow and fastened to the upper rim of the forearm piece and to the elbow block to ease the strain on the joints and to cushion the last few degrees of extension against jar and noise The upper arm piece is a hollow shell inside of which is the socket It is constructed of leather, metal, plastic, or, less preferably, of wood It is tubular in shape at its distal end where the elbow block is maintained, but its medial aspect is gradually flattened as it extends upward so that a cross section of it at the level of the deltoid insertion would appear as a half circle, the medial portion representing the diameter The inner rim of the socket is relieved to accommodate the pectoralis major and latissimus dorsi muscles which form the anterior and posterior borders of the axillary fold, the outer portion is molded upward over the deltoid muscle for an inch or two in order to limit the rotation of the prosthesis The stump, when placed within the socket, should lie clear of the elbow block and should be in gentle contact with the sides of the socket throughout so that there will be no free play to diminish the effectiveness of the transmission of power to the prosthesis There are several types of harness, or suspensory apparatus, the most common of which is the simple "figure eight It starts on the front of the upper arm piece passes over the shoulder as a broad band, and crosses the back to the opposite shoulder, there it is carried under the axilla, this portion being well padded and brought upward over the

shoulder to recross the back and be fixed to the pull cord, or to the arm piece at the posterolateral border. The bands are stitched where they cross in the back to keep them from slipping.

There are three above-elbow prostheses which have just passed through the experimental stage and have recently become available commercially. They are the Northrup Above Elbow Prosthesis, the Fitch Dual Control Arm, and the Hosmer Arm. Their development was sponsored by the Committee on Artificial Limbs of the National Academy of Sciences in cooperation with the Army and the prosthetic research programs of the Army, Navy, and Veterans Administration. Each contains the parts found in the standard prosthesis but is modified by special mechanical features which set it aside from the conventional limb.

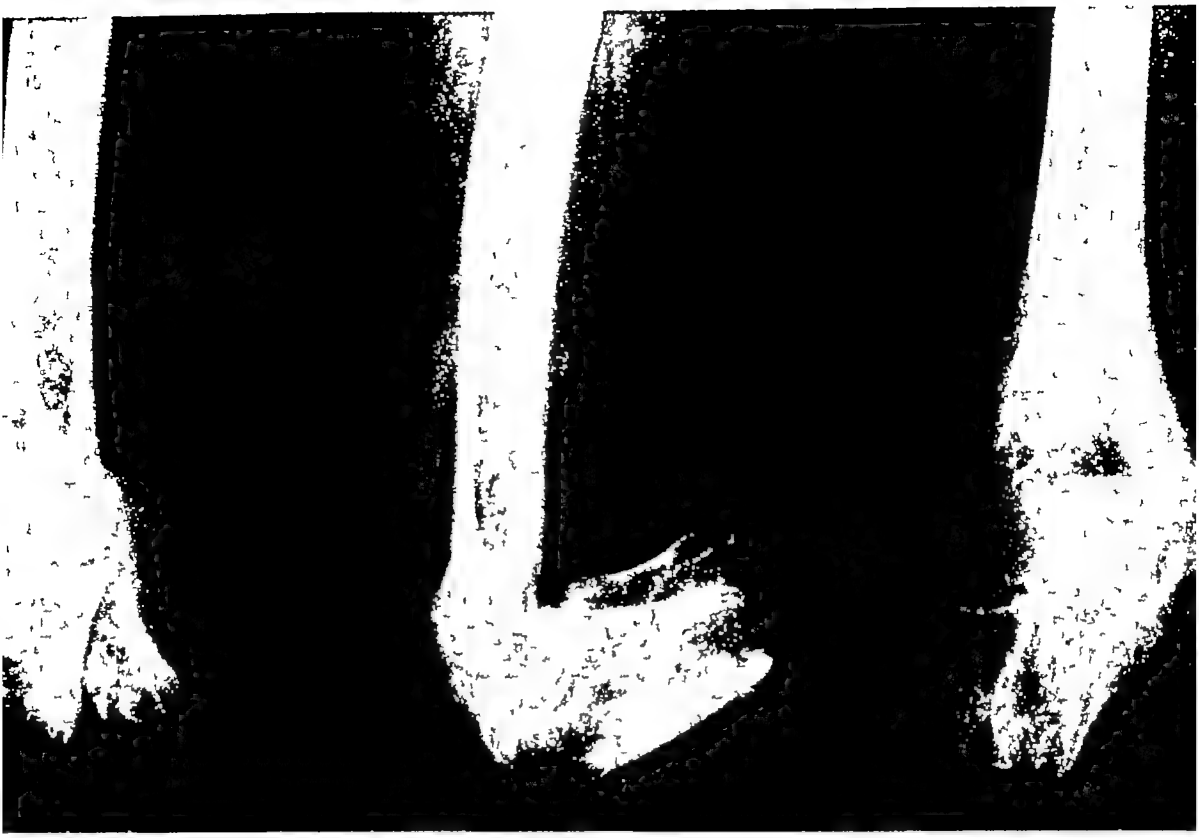
ADAPTATION OF PROSTHESES TO SHORT BELOW-ELBOW STUMPS


352


353

Figs. 352 and 353.—A short stump after lengthening transplantation of a small portion of radius to the ulna in order to allow fitting with a standard below-elbow limb. (Walter Reed General Hospital Neg. Nos. 4462 2, 4416 A6.)

Figs. 354-358.—Short below elbow stump made practical for fitting with a prosthesis through section of the biceps tendon. Illustrations demonstrate the range of motion. Fig. 354. In the x rays. Figs. 355 and 356. Without the prosthesis. Figs. 357 and 358. With the prosthesis. (Courtesy of Drs. H. C. Blair and H. D. Morris.)



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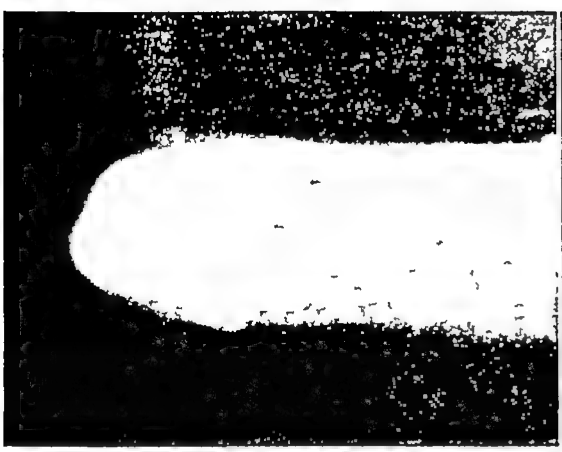

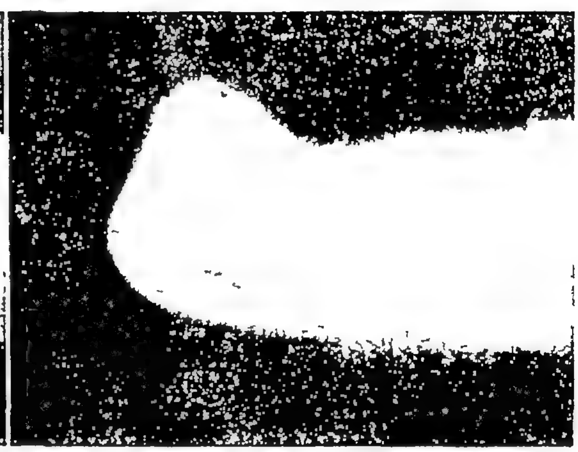

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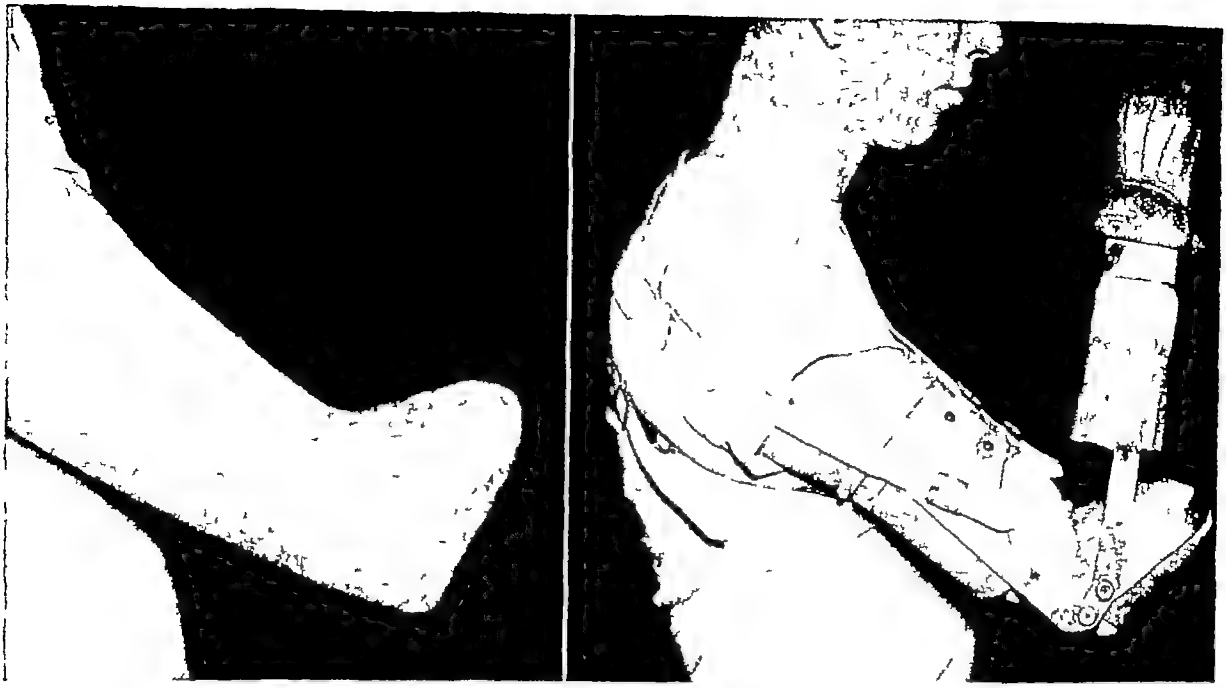


359 360

Figs 359 and 360—Short below elbow stump fitted with a prosthesis with motion multiplying elbow hinge Note the limited flexion of the stump, and the increase in flexion gained by the use of the special hinge (Walter Reed General Hospital Neg No 4851 2,4)

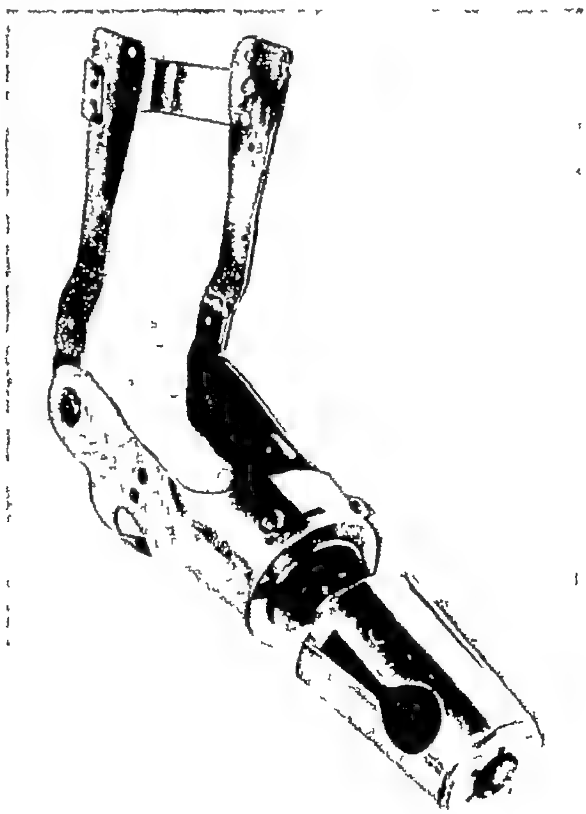


Fig 361—A special prosthesis for the short below elbow stump in which the distal end of the frame can be detached to afford better leverage for work activities The distal end of the frame is used chiefly for dress (Courtesy A J Hosmer Corp)

As is true of all prostheses, these limbs should not be prescribed until a thorough study has been made of the individual needs of the amputee

The Northrop above-elbow prosthesis has three unique features: an elbow locking device, operated by shoulder shrug which affords stability in any one of twenty-three different positions of flexion, a turntable mounted immediately above the elbow which allows varying degrees of rotation of the forearm upon the arm piece, and a special Northrop cable to transmit power to the artificial hand which permits 30 to 35 per cent more efficiency than the usual rawhide pull cord For the unilateral amputee, the limb has three separate control systems flexion of the elbow is effected by the forward movement of the stump, the locking and unlocking of the elbow mechanism are accomplished by a downward shrug of the shoulder on the amputated side, and activation of the hand is provided by the forward shrug of the opposite shoulder For the bilateral amputee the harness is simplified to the use of two pull cords, one for operation of hook or hand and one for control of the elbow locking device, with this modification he can put on his limbs unaided This Northrop arm is made of laminated plastic It can be washed with soap and water, does not absorb perspiration odors, and is extremely light, weighing only two and one-half pounds complete with harness and seven ounce hook

The Fitch Dual Control Arm, developed at the Mare Island Naval Hospital, utilizes cable also, has a new development in shoulder harness, and presents a new type of forearm control This last consists of a cable system which allows both flexion and extension to be effected by movements of the stump There are two cables, one attached to the anterior and the other to the posterior aspect of the shoulder harness, which pass downward within the upper arm section and cross, passing through a roller mechanism at the upper end of the forearm, the anterior cable is then attached to the posterior aspect of the forearm piece, and the posterior one is fixed to the anterior aspect of that part When the stump moves forward, the arm is flexed, when it moves backward, the forearm is extended This arrangement has three very definite advantages (1) it maintains the stump firmly within the socket, (2) it affords direct control of the forearm piece by the stump, and (3) it provides the prosthetic forearm with power equal to that of the stump There is one other cable, the one which activates the hook or hand by harnessing the shrug of the opposite shoulder in the conventional manner Light aluminum alloy is used in the construction of the arm, and the socket is made of "Celastic" covered with leather The weight of the arm complete with harness and hook is two pounds and seven ounces

The Hosmer artificial arm is similar to the Northrop arm in that it makes use of cable control and has an adjustable turntable to position the forearm It has a different elbow device, however, which locks in an unlimited number of positions and will lock or unlock under load applied to the forearm It is also equipped with a button at the wrist which permits quick interchange of hand hook, or work appliances The Hosmer arm is constructed of light aluminum alloy and laminated plastic Its over-all weight is two pounds including harness and seven ounce hook

The standard working arm is used for the upper arm stump of any length from the long one resulting from elbow disarticulation to the short one of two or three inches (This measurement is taken from the anterior axillary fold in accordance with the method used by the limb fitters) However, the problems in adapting it to the long stump in which the humeral condyles remain are vastly different from those encountered in fitting it to the supracondylar stump in which no bony expansion is present

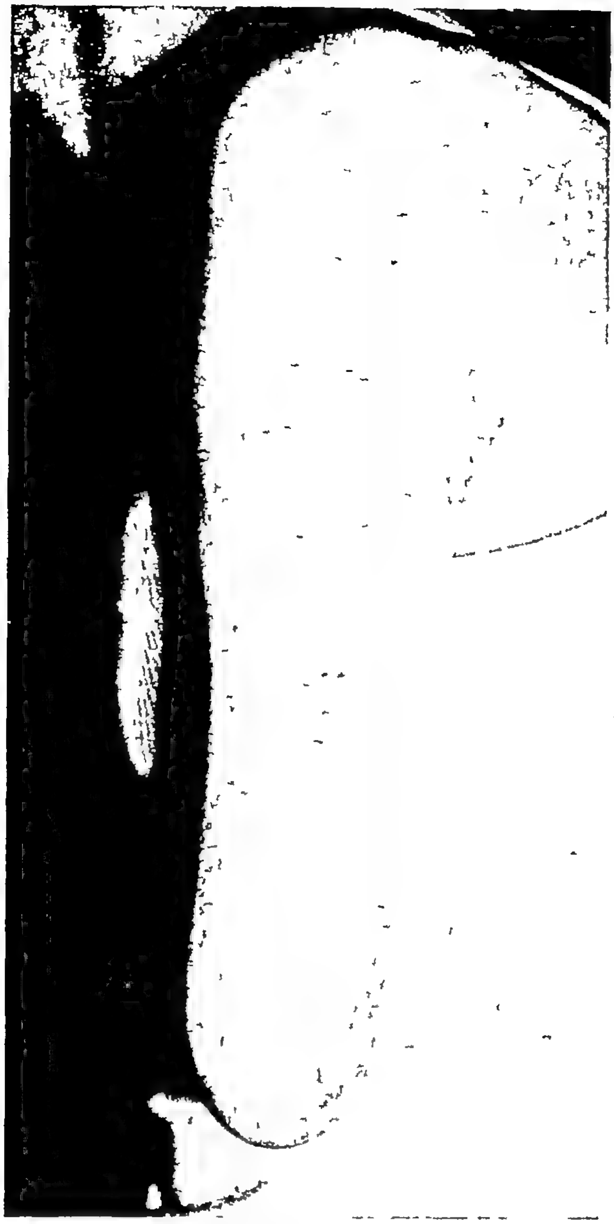
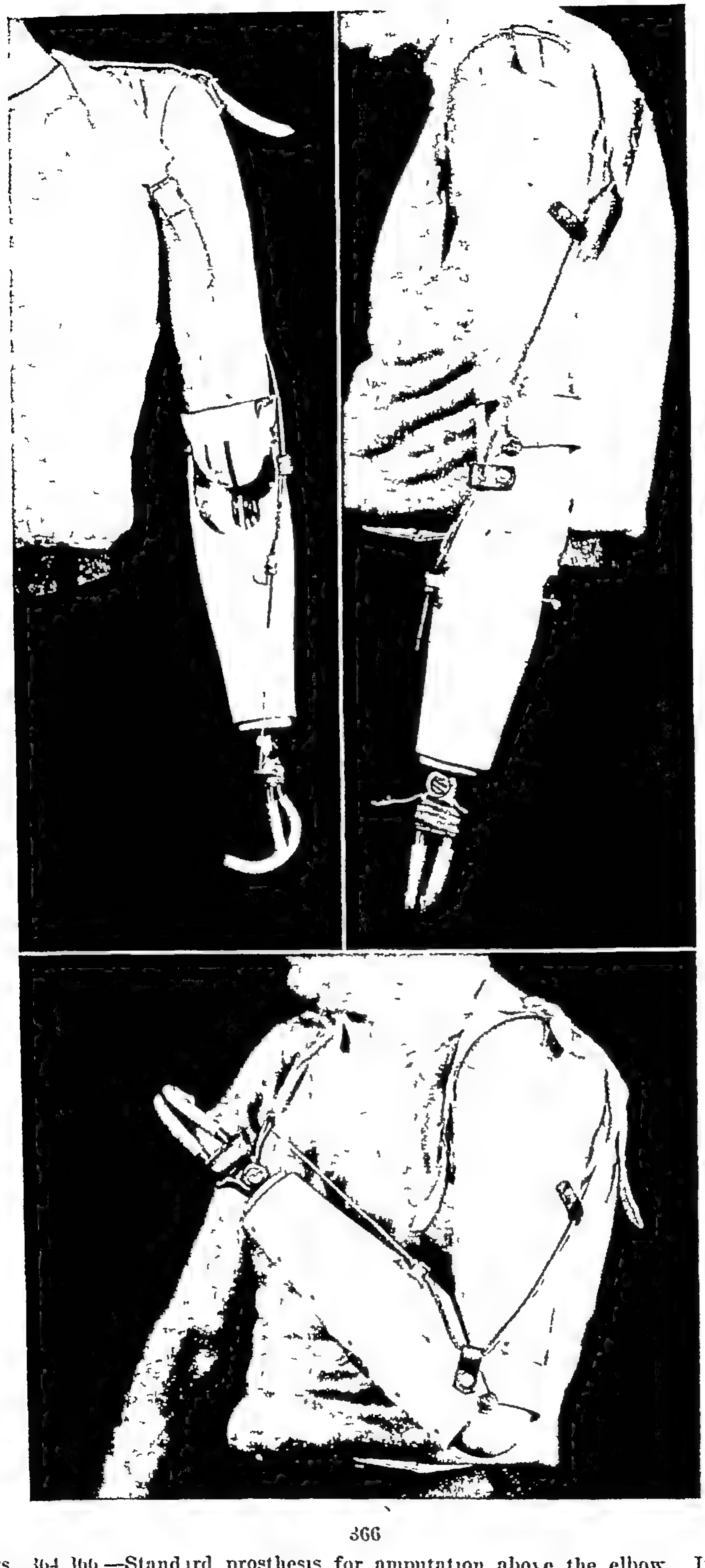


Fig 362—Stump of ideal length Note the long powerful lever arm with terminal scar, and gently rounded end (Walter Reed General Hospital Neg No 4680 1)

Fig 363—Amputation of the middle third of the humerus Adequate stump length is still present for the standard prosthesis (Walter Reed General Hospital Neg No 4307 1)

364 365



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Figs 364-366.—Standard prosthesis for amputation above the elbow. Its principal parts are the socket (which receives the stump), the elbow block, forearm piece, hook, pull cord, and harness. The elbow is flexed by forward motion of either the stump or opposite shoulder. When the elbow joint is not locked, the hook is not activated until flexion is complete. The elbow joint may be fixed in the desired degree of flexion by switching the lock on the back of the forearm piece to allow direct action of the pull cord on the hook. (Walter Reed General Hospital Neg. No. 4893-3 1 2.)

In the first instance, when elbow disarticulation or transcondylar amputation has been performed, there is the ever present threat of a tender, painful stump because of the pressure of the prosthesis upon the skin and tissues overlying the bony prominence of the condyles, there is the necessity of lacing the socket together when the prosthesis is to be worn because the flaring nature of the stump will not allow it to slip into place otherwise, and there is the difficulty

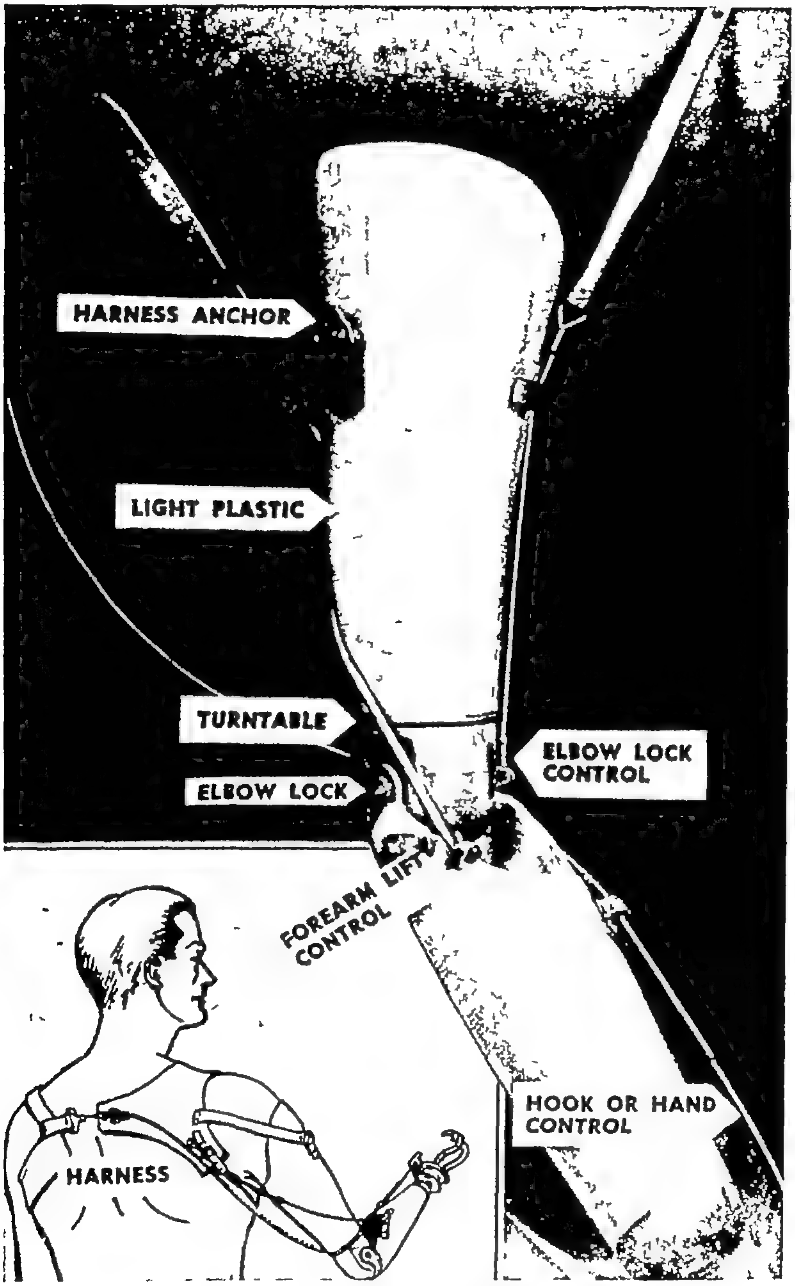


Fig 367—Northrop Above Elbow Prosthesis (Courtesy of Veterans Administration)

of creating a limb large enough and long enough to encase the bulbous stump end and accommodate the elbow joint without losing all proportion and symmetry As to the tenderness of the stump, there is nothing to ensure against it, but every precaution should be taken by using the most meticulous care in the molding of the socket As for the bulk and length of the prosthesis, as yet no

satisfactory way has been found to avoid it The socket must be abnormally large to fit about the condyles, and the standard elbow block must extend below the level of the normal elbow joint because of the long stump In an effort to obviate this disproportionate length a modification of the standard limb has been made Instead of the usual upper arm shell contoured within to fit the stump a molded leather socket of the type used on the forearm stump is employed, in

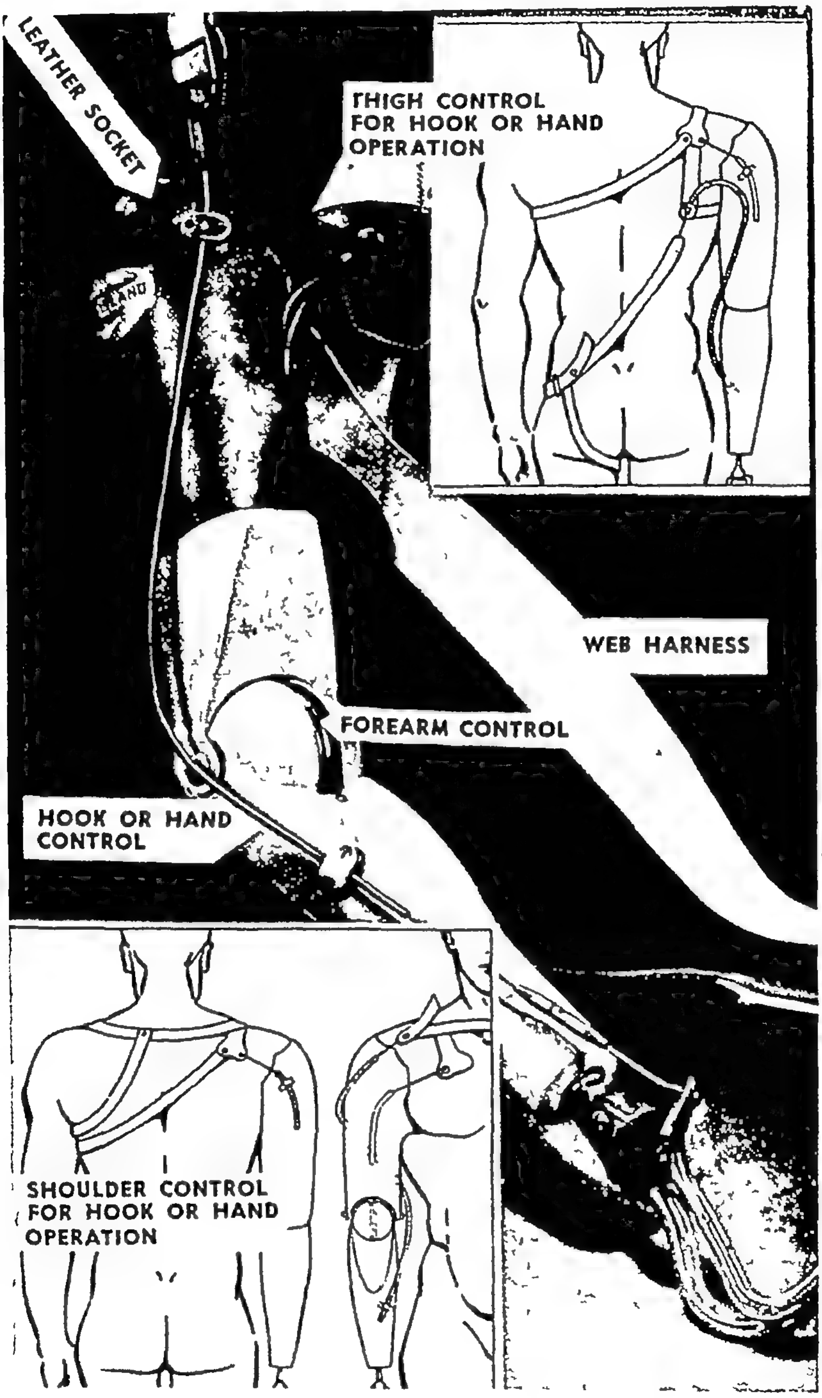


Fig 368—Fitch Dual Control Arm (Courtesy of Veterans Administration)

place of the elbow block lateral hinges with recently developed stop mechanisms are fastened on either side of the socket by metal supports This is hardly a satisfactory solution to the problem for although the abnormal length is avoided the lateral hinges fixed onto the already overlarge socket result in an elbow of undesirable breadth If a good fit can be obtained and if the bulk or excessive

length of the elbow joint can be overlooked, a prosthesis at this level has one advantage over that above the elbow, namely, that the expansion of the humeral condyles affords some stabilization against rotary motion. Nevertheless, I feel that except in the occasional instance, the elbow length stump, equipped with the prosthesis at its present stage of development, is not satisfactory from a fitting standpoint, and that the supracondylar amputation at the ideal level with the conventional prosthesis is to be preferred.

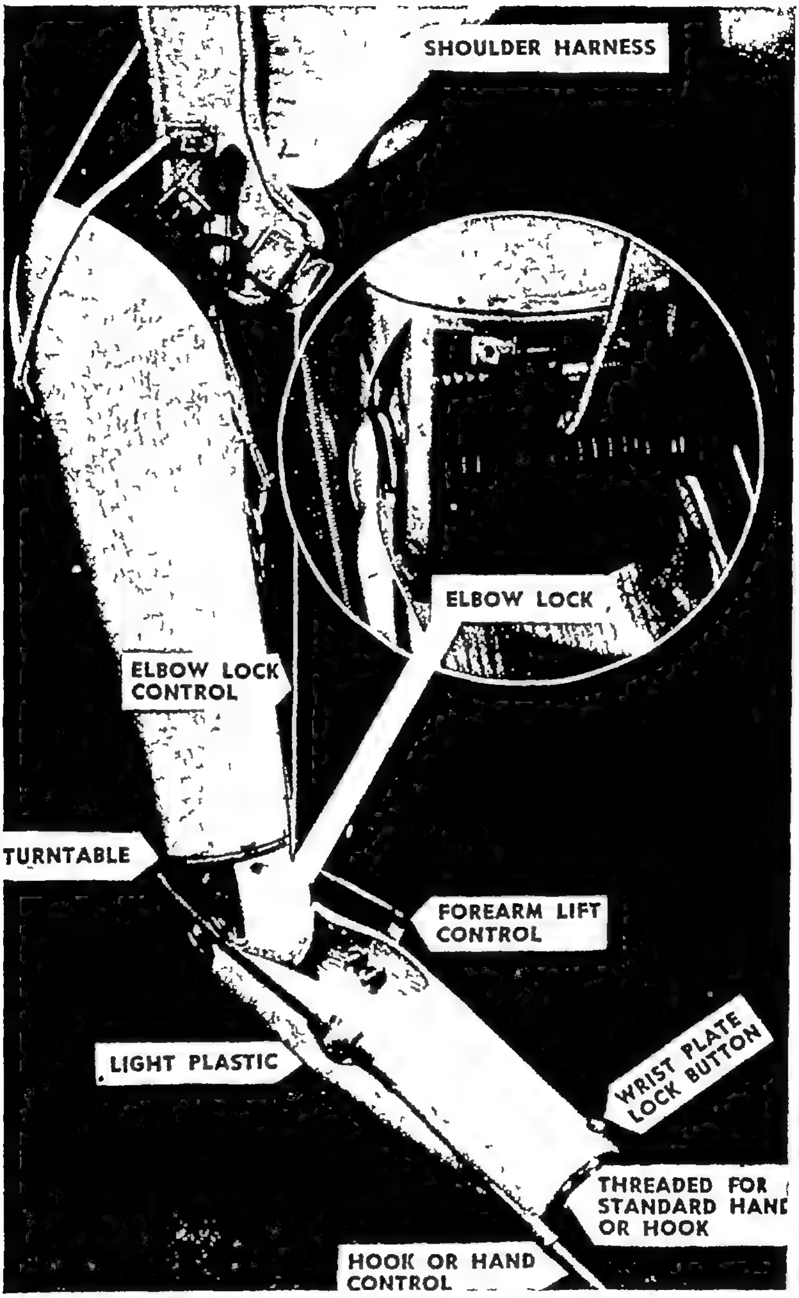
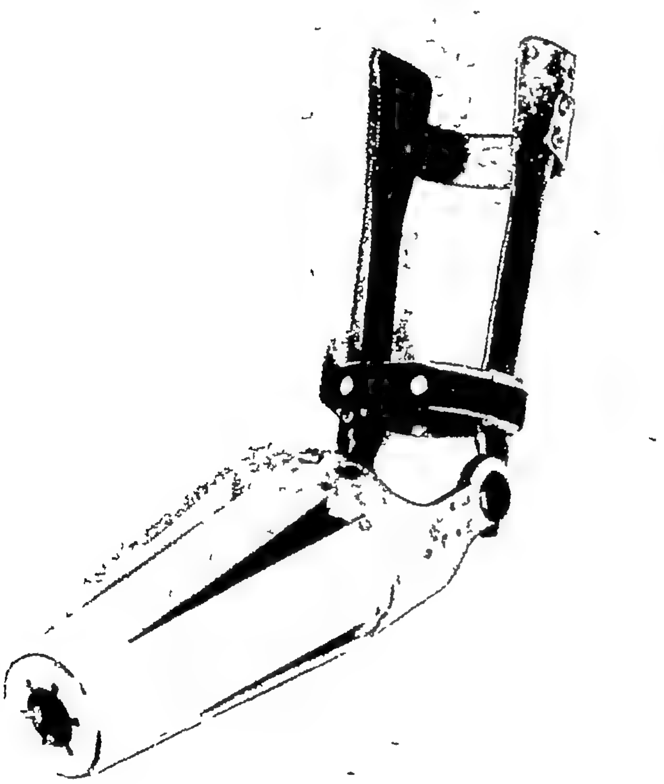


Fig 369—The Hosmer Above Elbow Arm. (Courtesy of Veterans Administration.)

In the second situation, when the arm has been severed above the condyles, there is the problem of stabilizing the rotary motion of the prosthesis which has no bony prominence to grasp but must cling to skin and tissues which are grouped about a single, pipelike bone. This tendency toward rotation can be

minimized by careful molding of the socket, and the inward deviation which occurs during abduction can be lessened by attaching the pull cord on the lateral aspect of the arm, rather than on the medial Even in the short stump of two or three inches, where rotation is quite pronounced, it can be largely corrected by extending the socket high over the deltoid muscle, attaching the cord on the lateral side of the socket, and fitting the limb with meticulous care The contour and the length of the stump above the supracondylar level make it possible for the upper arm piece to taper gently, simulating the form of the normal arm, and to accommodate the elbow block easily without noticeable extension In short, the fit, the function, and the appearance of the upper arm prosthesis are far more satisfactory at this level than when adapted to amputation immediately about the elbow



SQUARE TYPE ELBOW DISARTICULATION HINGES

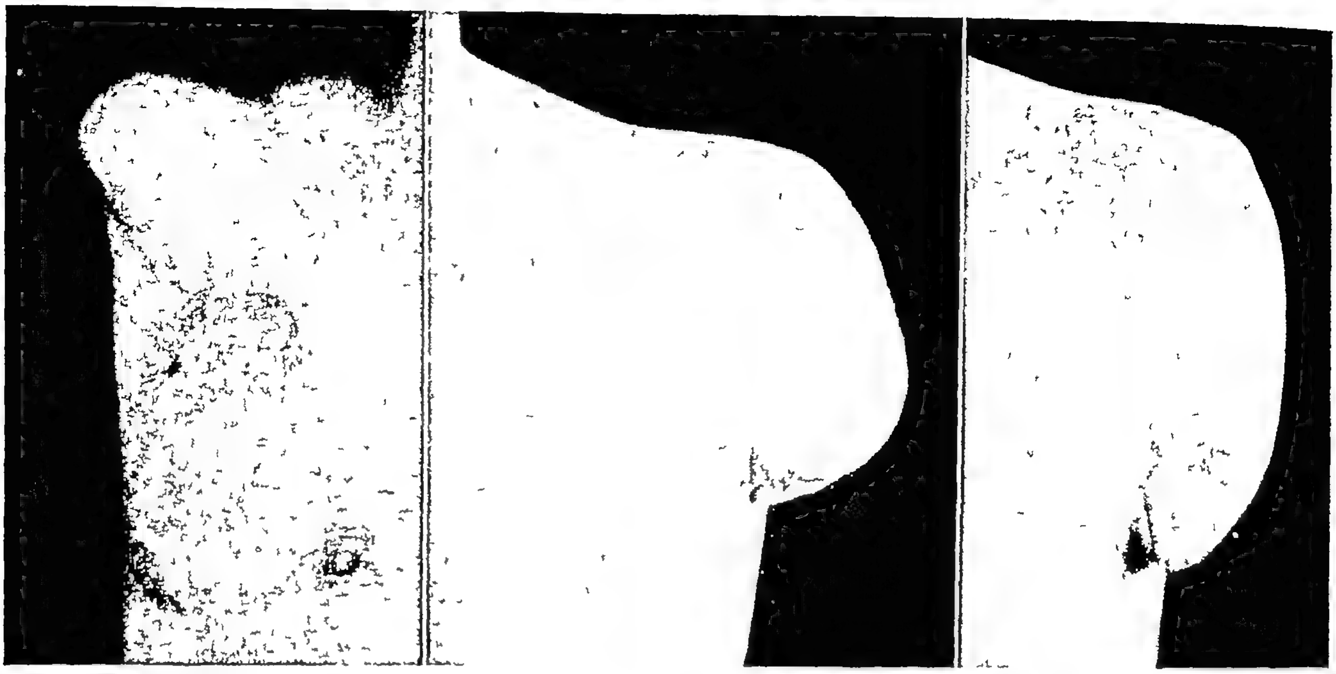
RATCHET TYPE ELBOW DISARTICULATION HINGES

Fig 370—Prosthesis for amputations about the elbow (Courtesy of A J Hosmer Corp)

Prosthesis for Amputations About the Shoulder

Amputations about the shoulder include severance through the surgical neck of the humerus, and shoulder disarticulation With both the motion of the shoulder joint is lost The prosthesis most commonly used at this level does not, at the present time, replace the active motion of this lost joint, but it is an improvement over that formerly used in that passive flexion and abduction are provided Although these motions are of little functional value in the use of the prosthesis, they do enable the amputee to move the arm away from the body and thus facilitate dressing The limb consists of the standard upper arm prosthesis fastened by a two plane hinge to a molded leather shoulder cap It is fixed to the body by a strap which is attached on the front of the shoulder cap

STUMP TYPES FOR WHICH SHOULDER DISARTICULATION PROSTHESIS IS USED



371 372 373

Fig 371—Shoulder disarticulation (Walter Reed General Hospital Neg No 4490 1)
Fig 372—Amputation through the surgical neck of the humerus (Walter Reed General Hospital Neg No 4646 1)
Fig 373—Amputation of upper third of the humerus with no functional stump length (Walter Reed General Hospital Neg No 4658 2)

PROSTHESIS FOR AMPUTATION ABOUT THE SHOULDER

374 375 376

Figs 374, 375, and 376—This consists essentially of an above elbow prosthesis attached to a shoulder cap by a metal hinge having motion in two planes A strap attached to the anterior and posterior aspects of the shoulder cap fixing the limb to the body and acting as a source of power The pull cord is attached to this same strap as shown above and is shortened through chest expansion (Walter Reed General Hospital Neg No 4356 1 2 3)

at the medial border and extends across the chest, under the opposite arm, and across the back As it nears the posterior aspect of the shoulder cap, it is fitted with a ring, through the ring a second strap is threaded, one end of which is fixed to the medial border of the cap and the other to the pull cord Thus, when the chest is expanded, the harness strap is tightened, and pull is exerted upon the cord Unfortunately the excursion of the strap and pull cord is limited so that the power transmitted from the chest is not sufficient to enable the artificial hand or hook to grasp or pinch with any force In addition the lack of active flexion, extension and abduction of the shoulder makes it impossible to move the hand from the side other than by slight flexion of the elbow joint Because of these limitations the hand or hook is useful only in holding action, as a partner to the normal hand, or as a weight to fix an object (as in holding a piece of paper while writing) This prosthesis is so wanting in utilitarian value, is so heavy and cumbersome of harness that it is seldom used after a short trial except for dress, or when there is a specific occupational demand

Prostheses for Forequarter Amputation

When the shoulder girdle is removed, the symmetry of the upper portion of the body is lost, for the skin follows the contour of the thorax Obviously an artificial limb at this level would be useless and undesirable, but there is a cos-

Fig 377.—Prostheses for forequarter amputation are designed to restore body symmetry and protect the lateral chest wall They are fixed to the body by a strap passing beneath the opposite shoulder (Courtesy of Dr E C Holscher)

metic shoulder prosthesis which can and should be used. It consists of a lightweight cap of leather or plastic, molded to resemble the normal form of the shoulder and fixed in position by a single strap which passes beneath the opposite axilla. This prosthesis serves two purposes: it disguises the deformity by replacing the normal shoulder contour and thus allowing the use of conventional clothing, and it affords a measure of protection to the soft, underlying structures.

Prostheses for Cineplastic Amputation

Cineplastic amputation is one in which motors are placed within the muscle bellies so that the action of the prosthetic hand is powered from the extremity itself rather than from a different part of the body. The construction of the prosthesis and harness necessarily varies at the different levels of amputation, but the artificial hand and the principle of power transmission are the same. The hand used almost exclusively at the present time is of German origin. It is usually made of lightweight wood or metal, and in it both thumb unit and finger unit have motion at the metacarpophalangeal joints. There are rubber pads on the finger tips to insure a firmer hold during pinch, and the hand can be placed in various degrees of pronation and supination by a small control which lies on the palmar aspect at the level of the wrist and which is manipulated by the opposite hand. The formation of the muscle motor has been described elsewhere in this text in the chapter on Surgical Techniques. Suffice it to say here that the sources of power are the muscles in which the motors lie, and that the transmitters of the force are stirruplike cords attached at one end to the ivory pegs passed through the motors and at the other end to the hand mechanism. Flexion action is motivated by the motor in the flexor muscle, and extension is powered by that in the extensor muscle. Where circumstances prevent the construction of one of these motors, its job is performed by spring action within the hand, and where the single pectoralis major motor is employed, the muscle powers the closing of the hand and spring action provides the force for opening it.

The below-elbow cineplasty is performed upon the stump which extends approximately to the junction of the lower and middle thirds of the forearm, and the motors are placed within the flexor and extensor muscles of that part. The prosthesis for the cineplastic procedure at this level consists of a molded leather socket which receives the stump, a distal forearm piece which is fashioned to resemble the lost portion of the extremity and to which the hand is affixed, and two steel shafts which extend along the medial and the lateral aspects of the two parts and serve to connect and reinforce them. Windows are cut in the socket at points which overlie the ends of the motors so that the ends of the ivory pegs can protrude and be free to follow the excursion of the muscles. The stirruplike attachments are fastened proximally to either end of each ivory peg and distally to the control mechanism of the hand. When both flexor and extensor motors are used, the stirrup connections between hand and pegs are sufficient to maintain the prosthesis on the forearm stump. When a single motor is used, some further harness may be necessary.

The above-elbow cineplasty may be performed upon the stump which still retains the elbow joint and a small portion of the forearm, or upon the one resulting from amputation as high as the junction of the lower and middle thirds of the upper arm. The prosthesis for it necessarily varies in construction according to the length of the stump to which it is adapted. If a short forearm stump remains, the forearm section of the limb consists of a molded socket which is about the stump and a distal forearm piece to which the hand is attached; the upper arm portion of the limb is a leather cuff which extends over the lower part

of the deltoid muscle and has windows through which the ends of the ivory pegs protrude. The three parts of the limb are connected and reinforced by steel shafts which extend along the lateral and medial aspects and which are hinged at the level of the elbow joint. Movements of the hand are powered by the muscle motors, cords with stirrup attachments connecting the ivory pegs with the hand controls; flexion and extension of the forearm are brought about by the normal elbow joint. If amputation is above the elbow, the forearm piece is a shell with hand attached and the upper arm portion is a molded socket with windows over the ends of the motors, which extends partially over the deltoid muscle. The two are joined by the usual reinforcing steel shafts which are hinged at the level of the elbow. The movements of the hand are activated by the muscle motors in the usual manner, but power for flexion and extension of the forearm, in this instance, is transmitted from the opposite shoulder by means of a conventional pull cord. The pull cord for this prosthesis, which is used only as a means of activating the elbow joint, is far more efficient than that for the conventional limb which must also control the motion of the hand.

When the above-elbow stump is too short to contain the muscle motors, the cineplastic procedure is performed upon the pectoralis major muscle and a single motor is used. In this situation the prosthesis is the same as that for the upper arm cineplasty except that the socket needs no windows, extends well up on the shoulder, and is short so that a distal upper arm piece is required, and a shoulder strap looped about the opposite shoulder must be used to fix the limb to the body. The power for flexion of the artificial hand is furnished by the single motor, extensoin being afforded by spring return; the usual ivory peg is used and the transmission cord with stirrup attachment passes from it to the anterior aspect of the socket near its upper border, and thence downward through a pulley system to the hand. The elbow joint is activated by force from the opposite shoulder; a pull cord loops about that part, crosses the back to the lateral border of the socket, and thence follows along the outside of the upper arm piece to be attached to the anterior aspect of the forearm piece. Its lateral position aids in preventing the rotation of the prosthesis.

As a surgical procedure, the cineplastic amputation is well tested and time proved, but from the prosthetic standpoint it is as yet unsatisfactory, for much of the muscle strength is lost in its transmission, with the result that the grip of the hand is weak and much of its usefulness is gone. In part, this can be contributed to the motor, for it cannot be constructed to take advantage of the full range of motion of the muscle, and consequently there is some loss of power at the end of the muscle excursion; in the main, however, the fault lies in the mechanical inefficiency of the artificial hand. Thus far, the development of this prosthesis has been almost nonexistent in the United States, the limited supply being copies of the German one or imports from that country. When improvements have been made in the mechanical details of the hand, and when the limb has become more widely available so that adjustments and repairs are less difficult to obtain, it should come into its own. For it does possess two real advantages over the conventional amputation prosthesis: with it the amputee gains a sense of proprioception and control, and with it little or no shoulder harness is required. Because of these particular qualities, it has been recommended for the bilateral amputee, but for him it presents one problem, that of placing the pegs in the canals and attaching the stirrups by himself. I feel that this operation has a great place in the future of the amputation field, and that the sound engineering of a suitable prosthesis is a must in the future development of artificial limbs.

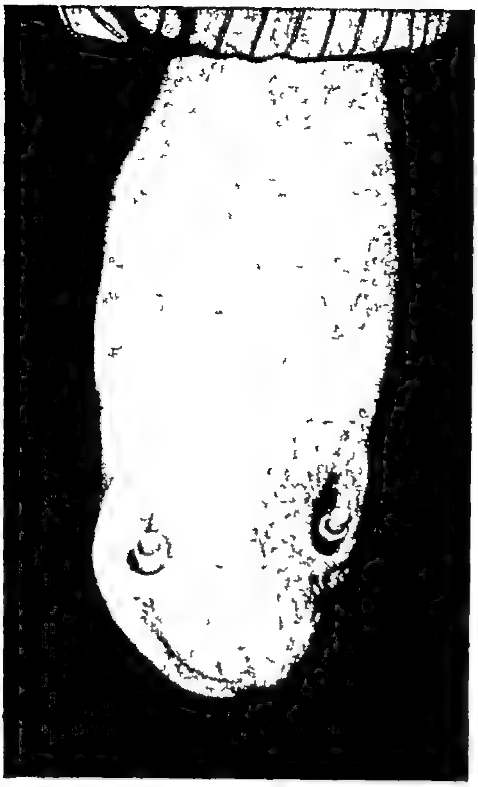


Fig 378—Forearm stump showing motors with pegs inserted (Walter Reed General Hospital Neg No 4966 A2)

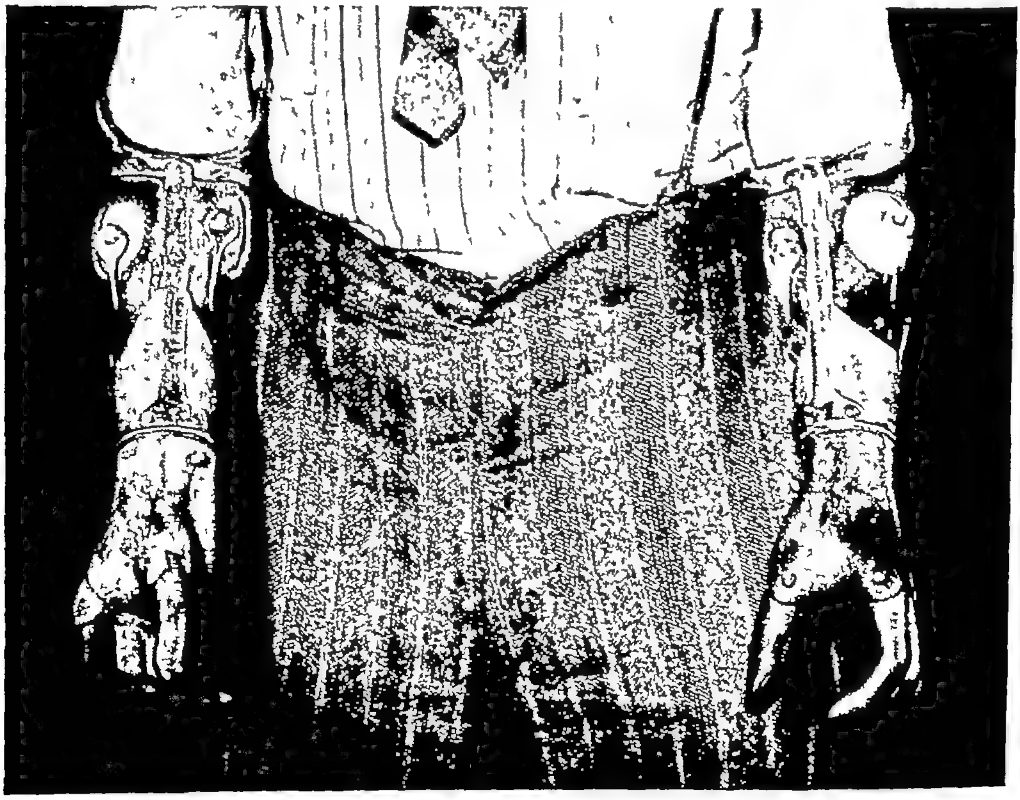


Fig 379—Bilateral below elbow cineplastic prostheses with flexor and extensor motors Note that the prostheses do not extend above the elbow, that pronation and supination is possible through *rotation of the hand at the wrist level, and that the pull cords* are fixed by a small stirrup which is attached to an ivory peg passing through the muscle canal (Walter Reed General Hospital Neg No 4966 A9)

Fig 380—The above elbow cineplastic prosthesis Note the flexor and extensor motors which are used to open and close the hand A pull cord is used for flexion of the elbow (Walter Reed General Hospital Neg No 4966 A10)

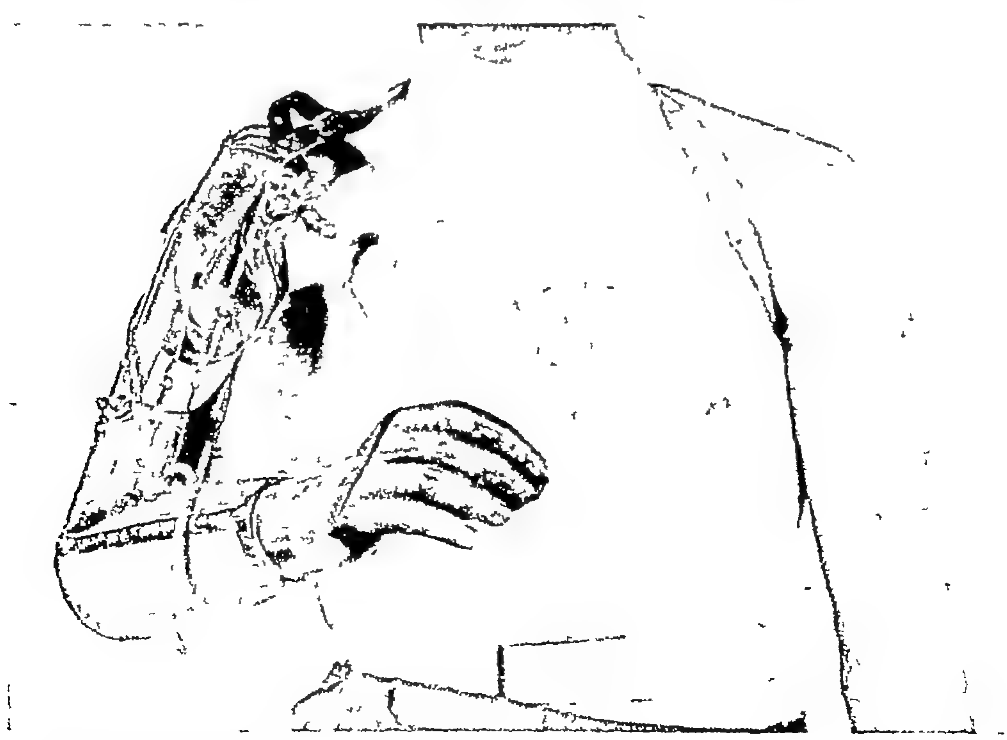


Fig 381—Short above elbow stump utilizing a cineplastic prosthesis with a pectoral motor for opening the hand which closes by spring return The elbow is flexed through a pull cord attached to the opposite shoulder (Walter Reed General Hospital Neg No 5076 1)

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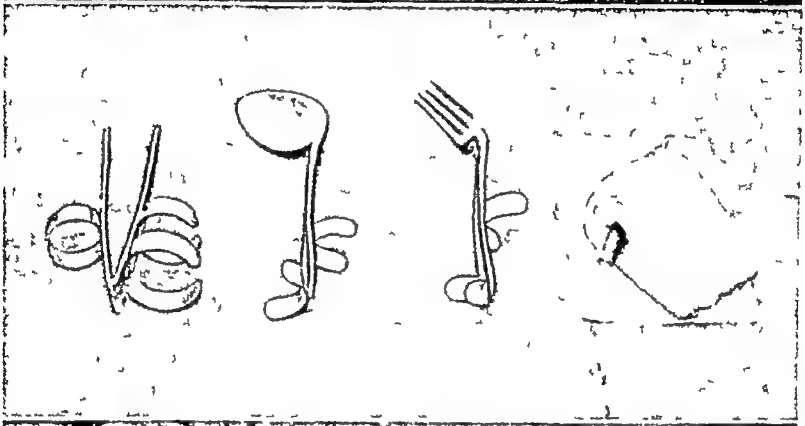

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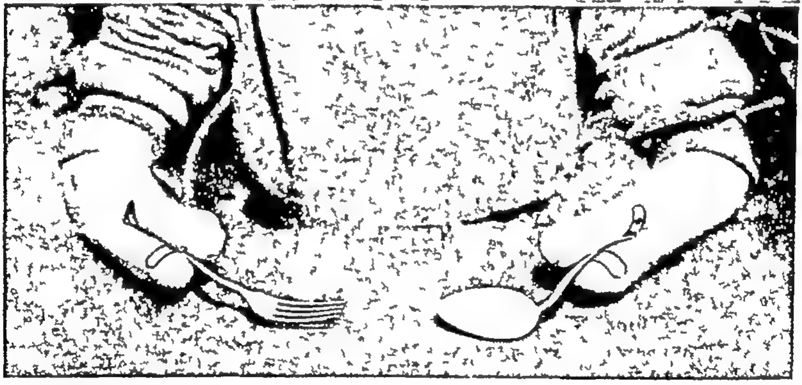

Figs 382, 383, and 384—Special appliances for use with the Krukenberg amputation (U S Army Medical Museum Neg No 91717, 91716, 91718)

PROSTHESES FOR THE LOWER EXTREMITY

The function of the normal lower extremities is to support and propel the body in stance and gait Each is composed of the foot, the leg, the thigh, and the joints that unite them Of these, no one part is functionally more important than another, but all combine to form a system of articulated levers The muscles of the trunk and the limbs themselves position these levers, stabilize their articulations, and provide the power with which they raise and lower the body, carry it forward, and maintain it in balance In these actions the two extremities complement one another, in standing and in lowering and raising the body, the weight is usually distributed equally between them so that no spinal curvature is present, in walking, one bears the body weight while the other is positioned, then the first provides the take-off or impetus which assists the second in assuming the weight and in levering the body forward in progress The normal course of these motions is easy and fluent

Since the purpose of an artificial limb is to substitute for the normal, it is evident that the goal of the lower extremity prosthesis is (1) functionally, to maintain the weight of the body in balance and provide it with locomotion, and (2) cosmetically, to approximate the form of the normal limb and the ease of normal motion Toward this end the standard artificial limb is designed to simulate an articulated lever system the sections between the joints are constructed to resemble the normal in length, size, and general contour, the joints are aligned and mechanically arranged to give the effect of normal motion The prosthesis is controlled by the muscles of the trunk and the amputation stump, but no attempt is made to duplicate the normal musculature which has been lost, therefore, the movements of the limb are mechanically different from those of the normal Instead of the flexion and extension of the articulations being brought about by muscle force, these movements are automatically effected by the pendulum motion which occurs when the limb is positioned by the stump, or they are impelled by a mechanical device, instead of the range of motion of the joints being limited and the limb being stabilized by normal musculature, these control measures are accomplished by bumpers, or stops, and by the specific placement and alignment of the artificial articulations

The extent to which amputee gait approximates the normal depends largely upon the proper alignment of the joints so that adduction and abduction are avoided, upon the correct length of the limb so that no distortion of body mechanics and posture is present, and upon the comfortable and efficient use of the prosthesis that is, it must be well-fitted to a stump which is healthy and capable of weight-bearing This last factor, the ability of the stump to bear weight, is exceedingly important, as it determines the level of amputation and the type and the fitting of the limb Normally the weight of the body is borne upon the metatarsal heads and the calcaneous—broad, flat surfaces covered with tough plantar skin When another area in the lower extremity must be found to carry this burden, there are two general choices (1) to amputate through a broad bony area where a relatively nontender integument is available and to create a wide smooth end which will bear weight directly against the bottom of the socket of the prosthesis (end-bearing), or (2) to amputate through the narrow shaft of the bone and allow a proximal bony flare to support the burden as it rests upon the upper border of the socket (proximal-bearing) In the latter instance some weight is carried by the soft tissues on the sides of the stump as they lie against the walls of the socket The amputation levels which are most practical for end-bearing are those employed in the Symes amputation, in knee disarticulation, in severance through the femoral epicondyles or supracondyles, or in the Stokes-Gritti procedure The bony prominences which provide satisfactory proximal-bearing are the flare of the upper end of the tibia, and the ischial tuberosity There is one very satisfactory amputation stump which cannot properly be placed in either of these classifications that is the short below-knee stump as it is used in a bent-knee prosthesis It is severed through the continuity of the tibia and fibula, but the leg is bent so that the weight is borne on the end of the knee joint

There are some differences in the artificial limbs and some special fitting problems peculiar to each of the two types of stumps and to each amputation level These will be discussed in the following pages No attempt will be made to describe the minute mechanical detail with which the surgeon is not concerned but rather an effort will be made to present the pertinent factors which will be of practical value to him in evaluating, fitting, and checking the various prostheses for the lower extremity

Prostheses for Amputations of the Forefoot

In the normal forefoot the articulations provide the flexibility which enhances the smoothness of the last phase of the step, and the musculature affords spring to the gait by giving stability and resilience

When amputation is performed through the toes or through the distal ends of the metatarsals, the flexibility of the foot is not noticeably impaired in normal walking and a sufficiently stable base still remains from which to push off However, tip-toe action is gone and some of the spring is lost from the final phase of the step, making running difficult There is no practical way of substituting for the tip-toe action, but its loss is of no great matter, being actually an inconvenience rather than a disability The resilience of the step, however, is important to the ease of both walking and running and it is well to recapture some of it This can be done by placing a strip of spring steel between the inner and outer layers of the sole of the shoe Frequently with amputation at this level, the toe of the shoe will collapse inward over the amputated area and press painfully against the tender dorsal skin To obviate this, an insole incorporating a felt toe piece may be fitted into the shoe, or a piece of felt may simply be placed within it distal to the amputation

Amputation through the proximal portion or the base of the metatarsal bones completely robs the gait of spring and "take-off" In addition, balance is somewhat impaired, although the shoe provides the normal length and breadth of the supporting surface, it lacks stability because it is unable to grasp the stub of the foot as firmly as it should The prosthesis for amputation at this level consists of an ankle corset and a metal arch support with a flexible felt or rubber toe piece In its construction the ankle corset is molded over a plaster replica of the foot and its upper border is just low enough to be covered by the usual high-topped shoe It is fixed to the foot plate to form a single unit

The Standard Artificial Foot

When amputation is performed at any level proximal to the base of the metatarsals, the arch support type of prosthesis with flexible toe piece is not sufficiently stable to substitute for the foot or the portion of the foot which is

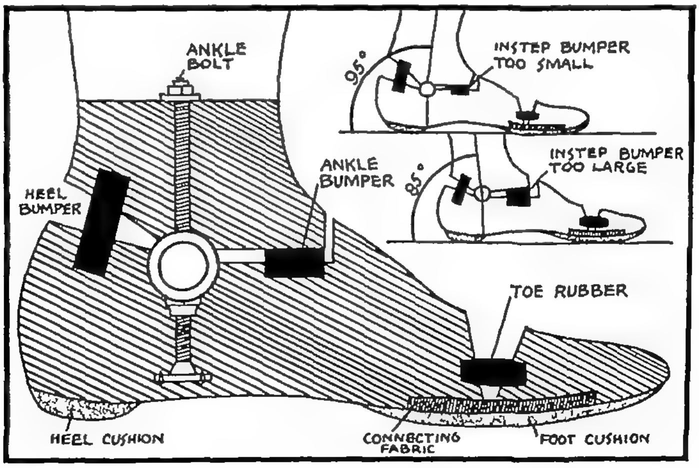

Fig 385—Schematic drawing of artificial foot and ankle joint

lost, and the standard artificial foot is used It is usually made of seasoned willow wood, rawhided for strength, and, in order that it may be flexible, it is divided into two sections by taking a dorsal wedge from the metatarsal region,

the toe piece is connected to the main unit which forms the tarsus and heel by fixing each to a single sole of leather or cord fiber, a cylindrical piece of rubber (a bumper) is placed within the wedge to prevent excessive dorsiflexion, a task normally assumed by the long flexor muscle. The foot is shaped to follow the general contours of the normal opposite foot so that a regular shoe can be worn, and is encased in leather for the sake of cleanliness and appearance. The plantar surface of the heel and of the ball of the foot is padded with sponge rubber which has a cushioning effect and affords some resilience to the step.

The proper alignment of the joints of the artificial member is a highly important factor in its comfortable and efficient use and should always be noted in the routine limb check. There is some controversy as to the angle at which the metatarsal wedge should be placed in relation to the long axis of the foot, but it is generally agreed that it is not necessary to duplicate the obliquity of the normal metatarsophalangeal joints, for the pattern of gait in the artificial foot is different from that in the normal. In my opinion the degree of obliquity should be slight, for otherwise the amputee tends to be thrown off balance laterally as the weight passes through the toe piece. This can, of course, be adjusted to the individual. The artificial foot itself is placed in external rotation with reference to the shin in a degree comparable to that of the opposite normal foot in the standing position. Internal or external rotation of the foot after final adjustment is seldom due to defects of the foot or its attachment but is usually caused by rotation of the entire prosthesis from above through faulty application.

Prostheses for Amputations Through the Tarsus

Normally the tarsus acts as a bridge between the two weight-bearing points of the foot, the metatarsal heads and the calcaneous, and apportions the burden between them. Within it lie the insertions of the muscles which control the ankle joint and thereby position the foot and regulate the angle at which the body weight is borne upon it.

When the older procedures of Chopart, Lisfranc, etc., are performed through the tarsus, the anterior pillar of support, the metatarsal heads, is lost and the structures of the tarsal region drop, in addition, the insertions of some of the governing muscles are severed and muscle balance and ankle motion are seriously disturbed. The usual result is equinovalgus or equinovarus deformity, conditions which are highly incompatible with normal stance and gait and which present a stump impossible to fit with a prosthesis. In the rare instance when the structures retain their normal relationship, a prosthetic device can be used, but since the stump requires considerable stabilization, no attempt is made to provide motion in the ankle and midtarsal joints, and the resultant gait is stiff and heavy. These procedures have become virtually obsolete in recent years, but very occasionally the surgeon and limb maker will be confronted with one which can use a prosthesis. Of these the most common is the Chopart. For it, only the toe piece and a small distal portion of the tarsal heel unit of the artificial foot are used because of the length of the stump. This foot piece is fixed by reinforcing steel bands to a molded leather socket which extends to the upper third of the tibia and opens posteriorly to receive the stump. I have seen only one case with a Chopart amputation (of twenty-three years' duration) in which the patient walked well. It is interesting to note that although gait was fairly good in this case with the artificial member, it was poor without it.

The Boyd amputation, a recent procedure for midtarsal amputation, successfully avoids the deformities usual at this level by removing the talus and fusing the calcaneous and the tibia. It was primarily devised for the patient

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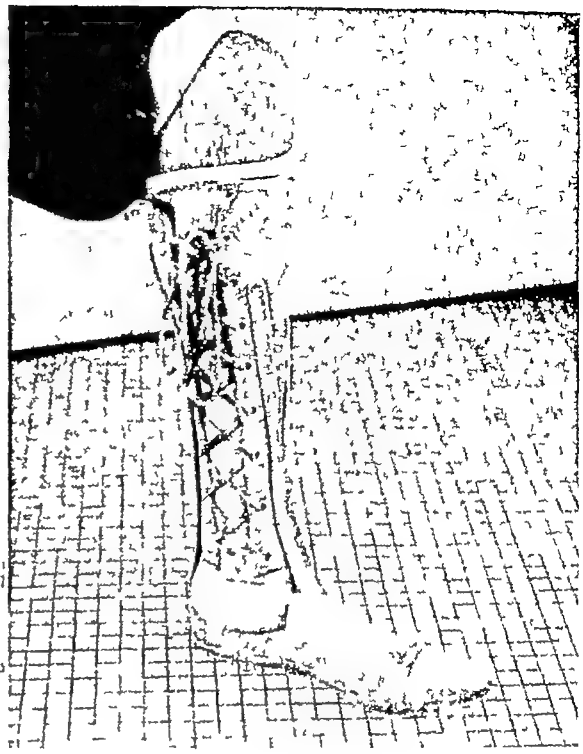

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Fig 386—The stump Note the broad weight bearing surface (Courtesy of Boyd, H B J Bone & Joint Surg 21 997, 1939)

Fig 387—The prosthesis Note the medial lacing on the leg corset to admit the stump, the reinforcements on the front and back of the leg, and the broad weight bearing surface upon which the end of the stump rests Gait is improved if an additional wedge, similar to the toe break, is placed at a point corresponding to the tarsal metatarsal region (Courtesy of H B Boyd)

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Figs 388 and 389—Anteroposterior and lateral x rays showing the calcaneotibial arthrodesis (Courtesy of Boyd, H B J Bone & Joint Surg 21 997, 1939)

who could not afford a prosthesis or whose occupation made the use of one impractical It is usually encased in an "Elephant Boot" (so-called because it is shaped like the foot of an elephant) which is a molded leather corset with a durable material incorporated as the sole It is excellent from the functional standpoint when used in this manner, for the long stump is easily brought in contact with the floor and the plantar aspect of the calcaneous is an ideal weight-bearing surface, however, the "Boot" scarcely meets the cosmetic demand, especially in women, and gait, with it, is similar to that with a peg leg This amputation can be fitted with an artificial foot, but the calcaneotibial arthrodesis negates the normal ankle motion, and the length of the stump precludes the use of an artificial ankle joint To compensate for this deficiency, an artificial midtarsal joint is created in addition to the metatarsal This is a dorsal wedge, similar to the metatarsal toe-break which is taken at a level corresponding to the tarsometatarsal joint of the normal foot The foot is thus divided into three sections The posterior one is a shallow heel block which is incorporated in the molded socket If the socket is made of leather, a wooden heel block is employed, if it is made of plastic, that material is merely extended downward and molded into the desired form The socket itself extends to the upper third of the tibia and has either an anterior or medial opening from that point to the level of the ankle to allow the bulbous end of the stump to be placed within it The gait which results from the use of this prosthesis very much resembles that of the human foot with arthrodesis of the ankle

The Standard Artificial Ankle Joint

The normal ankle joint is the fulcrum of the upright lever (the leg) as the body is carried over it in a forward arc, and the musculature which governs it controls the extent of that arc and positions the foot It is evident that a truly satisfactory prosthesis for amputation which eliminates this joint must allow adequate range of motion and yet must provide some means of control so that the foot can be properly positioned and the body can be maintained in balance

In the standard artificial ankle joint there is an ankle base of wood, metal, or plastic, which is incorporated directly into the shin piece Through this a bolt passes downward and is mounted at the end with a transverse hollow rod This rod is called the "ankle bolt" It glides within a hollow sleeve which is recessed in a transverse slot in the upper surface of the posterior portion of the foot and which is mounted on a bolt which passes down through that piece Frequently a "U-bolt" is used instead of the sleeve to hold the rod in position directly within the slot of the foot piece Any surface of the foot piece which comes in contact with the moving ankle bolt is lined with a wear-resistant material There is a space between the foot piece and the ankle base, and two rubber bumpers are placed within it, one anteriorly and one posteriorly The anterior or instep bumper, locks the foot against dorsiflexion, its firm resistance substitutes for the restricting action of the gastrocnemius-soleus muscle group The posterior, or heel, bumper acts as a check upon plantar flexion in place of the anterior tibial muscle group When these two bumpers are properly adjusted, the foot lies at right angles with the leg As weight is brought upon the heel, the heel bumper is compressed and the ankle joint is extended, as weight is transferred forward, the instep bumper receives the pressure and the joint is seen to be in flexion Thus the movement of the artificial ankle joint is actually brought about by the pressure and release of pressure upon the two bumpers This is a sound substitute for the normal ankle motion

The conventional ankle does not make provision for the lateral motion of the normal subtalar joint which facilitates going over uneven surfaces and de-

creases the jar as the foot is placed on the ground There have been various devices, such as dash' pots, multiple springs, single or multiple rubber discs, which have allowed motion on two planes, but these have not been generally accepted because of the wear and instability The most successful version recently brought before the public is made of a large single rubber disk with cable attachments passing through its anterior and posterior ends to substitute for the instep and heel bumpers

In doing a limb check upon the prosthetic ankle it is most important to ascertain that the bumpers are properly placed and adjusted The anterior bumper should be firm and resistant and of such a size that dorsiflexion is checked at 90 degrees If it is too small, this action will not be limited sufficiently, and the result will be a calcaneous type of gait with awkwardness and lack of take-off If it is too large, the ankle will not be able to dorsiflex to the full 90 degrees and the foot will lie in an equinus position, this is very undesirable for it increases the apparent length of the leg and causes the patient to overflex the thigh in order to lift the foot clear of the ground, in addition, it tends to put him off balance, with the body thrown backward, while standing or during the weight-bearing period of gait The posterior bumper should be soft and resilient (Pure gum rubber is the ideal, although synthetic rubbers have been widely used in recent years, they are far less satisfactory) It should be adjusted to allow 20 to 25 degrees of plantar flexion If it is too small, the foot will not fall gradually to the ground as weight is placed upon the heel in the first phase of the step, but will drop abruptly with a slapping motion If it is too large, the foot at rest will be forced tightly against the instep bumper, often in excess of 90 degrees' dorsiflexion, and during gait the extension of the ankle joint will be slow and stiff

Prosthesis for the Syme Amputation

The good Syme amputation affords the most satisfactory end-bearing stump in the lower extremity and is always preferable to below-knee amputation in men The broad durable weight-bearing surface and the absence of harness above the knee provide comfort, endurance, and freedom of movement not found in amputations at higher levels In the past, the American limb maker has been reticent to fit this type of stump In recent years, however, he has used his ingenuity to overcome the two principal obstacles to construction—bulk and the small amount of space between the bottom of the stump and the floor, and the perfection of surgical techniques has provided for better stumps At the present time, any modern limb maker can build the limb which was once his nemesis

The Syme prosthesis most widely used is the Canadian one developed during World War I It employs the conventional artificial foot with the posterior portion made shallow to accommodate the long stump and the standard ankle assembly Its socket may be formed of leather, wood, or plastic When leather is used, the socket is molded to a plaster replica of the stump and is split longitudinally down the anterior aspect and transversely across the front of the distal end so that the bulbous end of the stump can pass within it and rest against the bottom The slit is laced together with a leather thong With this leather socket, the ankle base is not directly incorporated but forms the distal portion of a steel frame which extends up the medial and lateral aspects of the socket for reinforcement Because of the pliable nature of the leather, the socket is not constructed for any proximal support, but is planned for complete end-bearing When wood or plastic is used, the upper portion of the socket is flared slightly to form a base for the expansion of the tibia so that the prosthesis is partially proximal-bearing With these sockets the anterior portion is cut away from just

below the upper weight-bearing area to within an inch or two of the distal end to allow for the passage of the stump. This opening may be laced with a leather thong or closed by a strip of rubber stitched to either side. The wooden socket must be rawhided for strength and must have a metal ankle base fixed to it for the reception of the ankle bolt, while the plastic needs no reinforcement and the ankle assembly can be bolted directly to its distal end. Because the breadth of the ankle is thus materially reduced in the plastic socket, it is cosmetically superior to both the leather and the wooden. It is my opinion that after more experience is gained in the fabrication of the plastic socket it will be used almost exclusively.

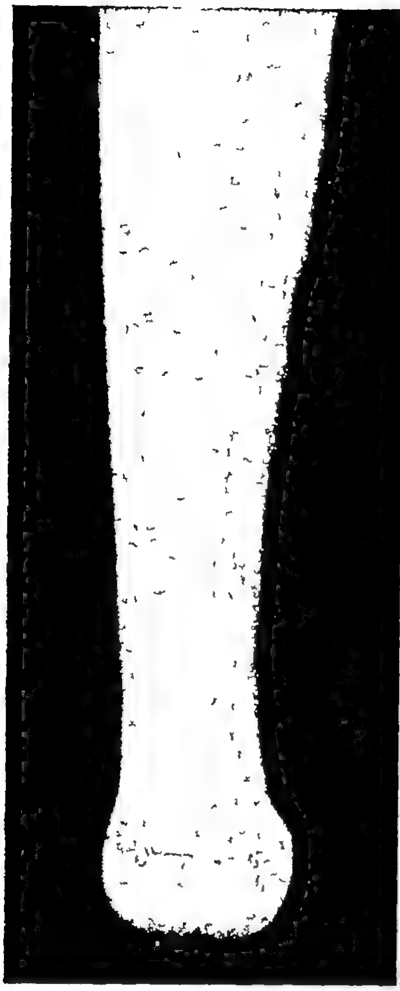
When the Syme amputation is performed at the ideal level, the bulbous stump end readily retains the prosthesis without any harness. When severance is carried out at a higher level so that the distal flare is lost, a cuff is usually placed above the knee, and the socket is suspended from it by side straps of leather. Occasionally a pelvic belt of webbing is used with a Y-strap extending from it to be fastened on either side of the socket.

The chief concern in doing a limb check on this prosthesis is with the proper arrangement of ankle and metatarsal bumpers, with the fit of the stump within the socket so that pressure is taken at the proper points and no rotation is present, and with the depth of the posterior portion of the foot piece which influences the over-all length of the stump.

Prostheses for Below-Knee Amputations

The leg, or shin, is the segment of the lever system which lies between the ankle and the knee. Normally it contributes necessary length to the extremity, contains the musculature which controls the ankle joint, and subsequently positions the foot and forms a transmitting link between the superincumbent body weight and the distal weight-bearing surface. When below-knee amputation is performed, i e, severance through the middle or upper third of the shin, these contributions to the function of the extremity are lost. A durable shin piece to which foot and ankle assembly are attached can replace the lost length, and the bumpers of the prosthetic ankle joint can substitute for the muscles of the leg which normally govern that joint and position the foot. But there is no distal bony flare to which the weight can be transmitted. Consequently the stump and the prosthesis must be planned for proximal-bearing. Because of the tapering shape of the stump, the limb cannot be maintained without a corset above the knee, and this in turn necessitates the use of a hinge at the knee joint so that normal knee motion will not be lost. In the early use of this prosthesis the muscles of the thigh are weak, either from recent surgery or from lack of use, and need some assistance in flexing and extending the knee and controlling the artificial limb. An anterior extensor strap and a posterior check strap are employed to fill this need and also to act as additional suspenders for maintaining the limb.

There is a difference of opinion as to whether tibial weight-bearing alone or in combination with ischial weight-bearing is the most desirable type of fitting for the below-knee amputation. While all admit that the patient walks better and is more comfortable with tibial-bearing, the proponents of ischial-bearing feel that advantage should be taken of every possible source of weight-bearing, namely, the expanding flare of the tibia, the circumference of the thigh as grasped by the corset, and the ischial tuberosity and adjacent gluteal shelf, if the amputation stump is to stand up best over a long period of years. The ischial-bearing limb requires a high thigh corset and has the disadvantages of



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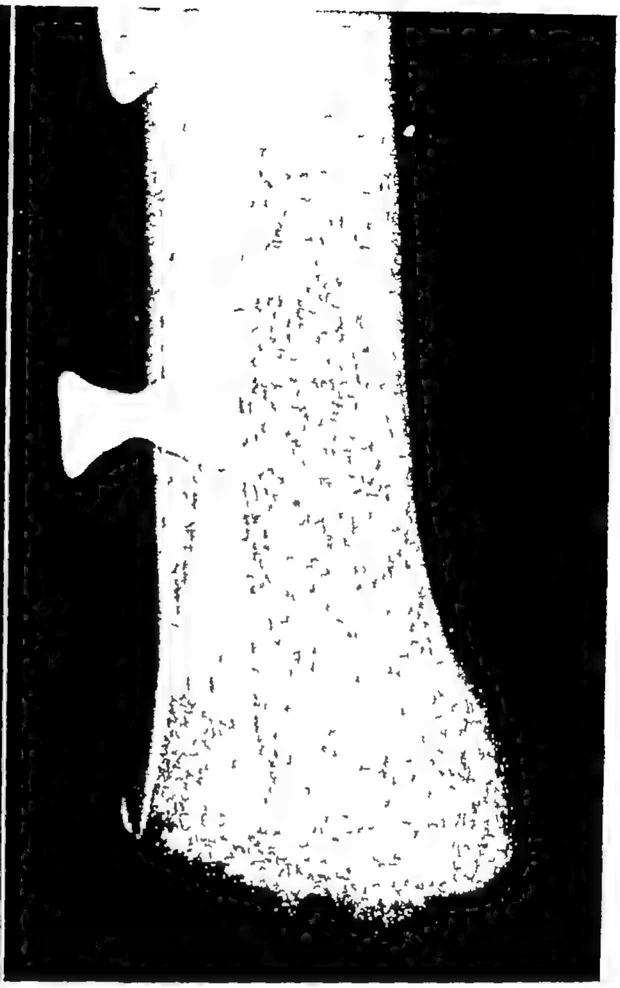

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Fig 390—The ideal stump (Walter Reed General Hospital Neg No 4924 3)

Fig 391—X-ray of the bone end, demonstrating the broad weight bearing surface, the rounded bone edges, and the bulbous bony contour of the end of the stump which aids in the retention of the artificial limb

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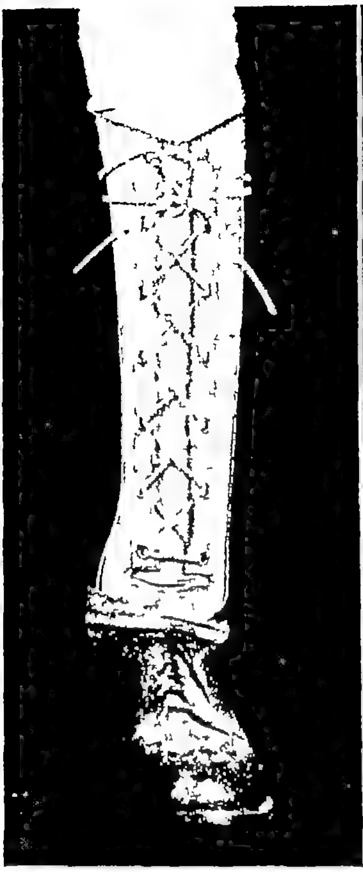
Fig 392 and 393—The prosthesis, anterior and medial views (Walter Reed General Hospital Neg No 4736-4, 1)

Fig 394—The Syme bedroom slipper (Courtesy of R H Alldredge England General Hospital Neg No SA 889)

Fig 395—X-rays of a satisfactory Syme amputation above the ideal bone level Note the lack of bony flare (Walter Reed General Hospital Neg No 4667-5)

Fig 396—Prosthesis for the same case Note the additional harness above the knee necessary to retain the prosthesis



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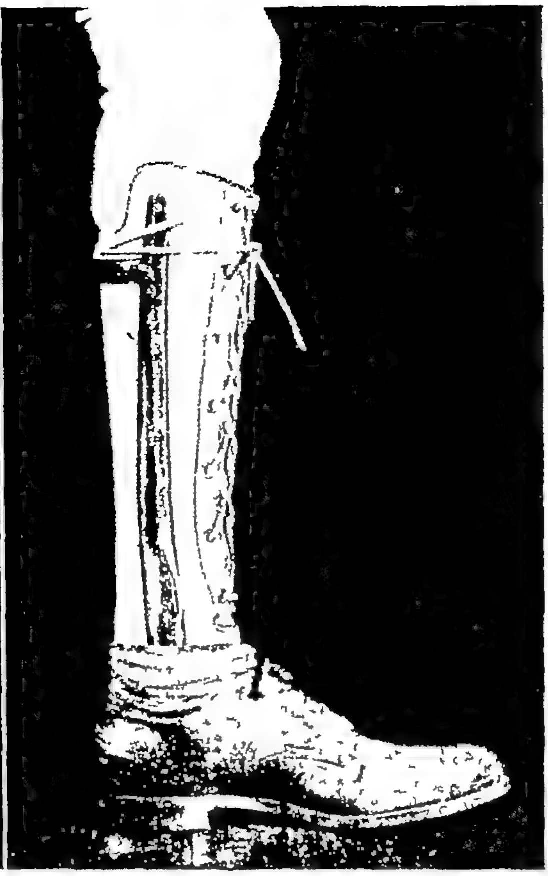

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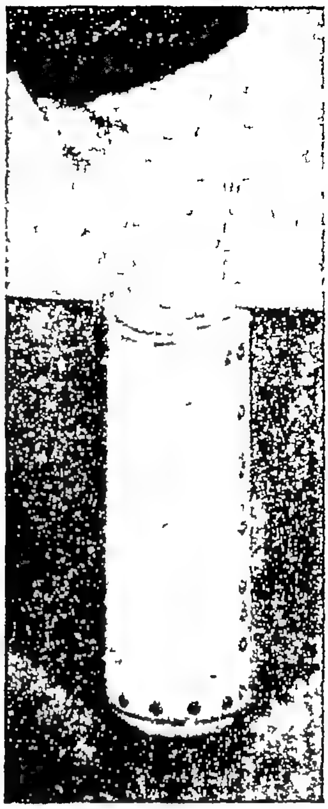

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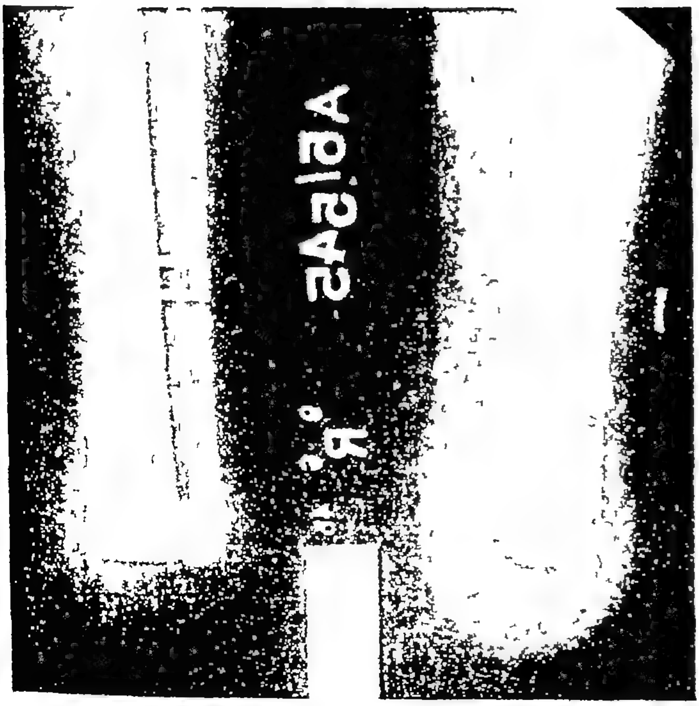

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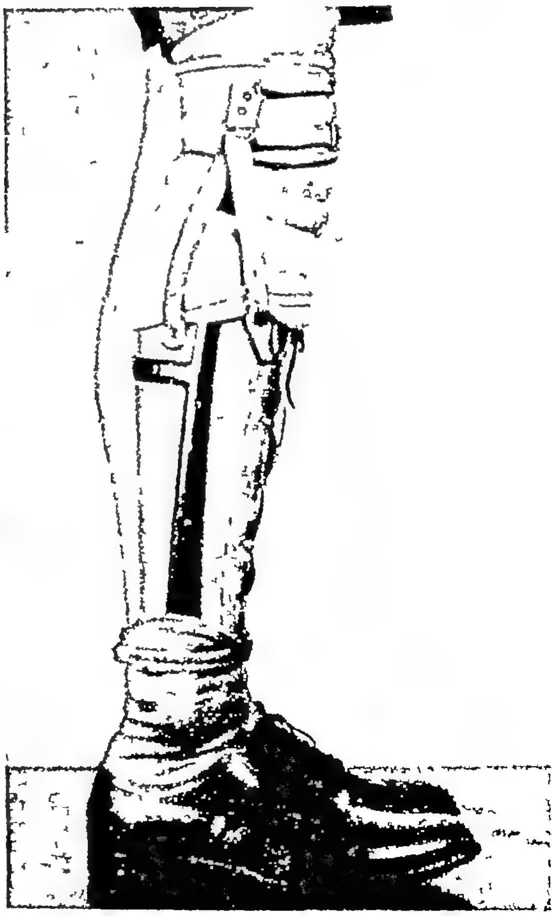

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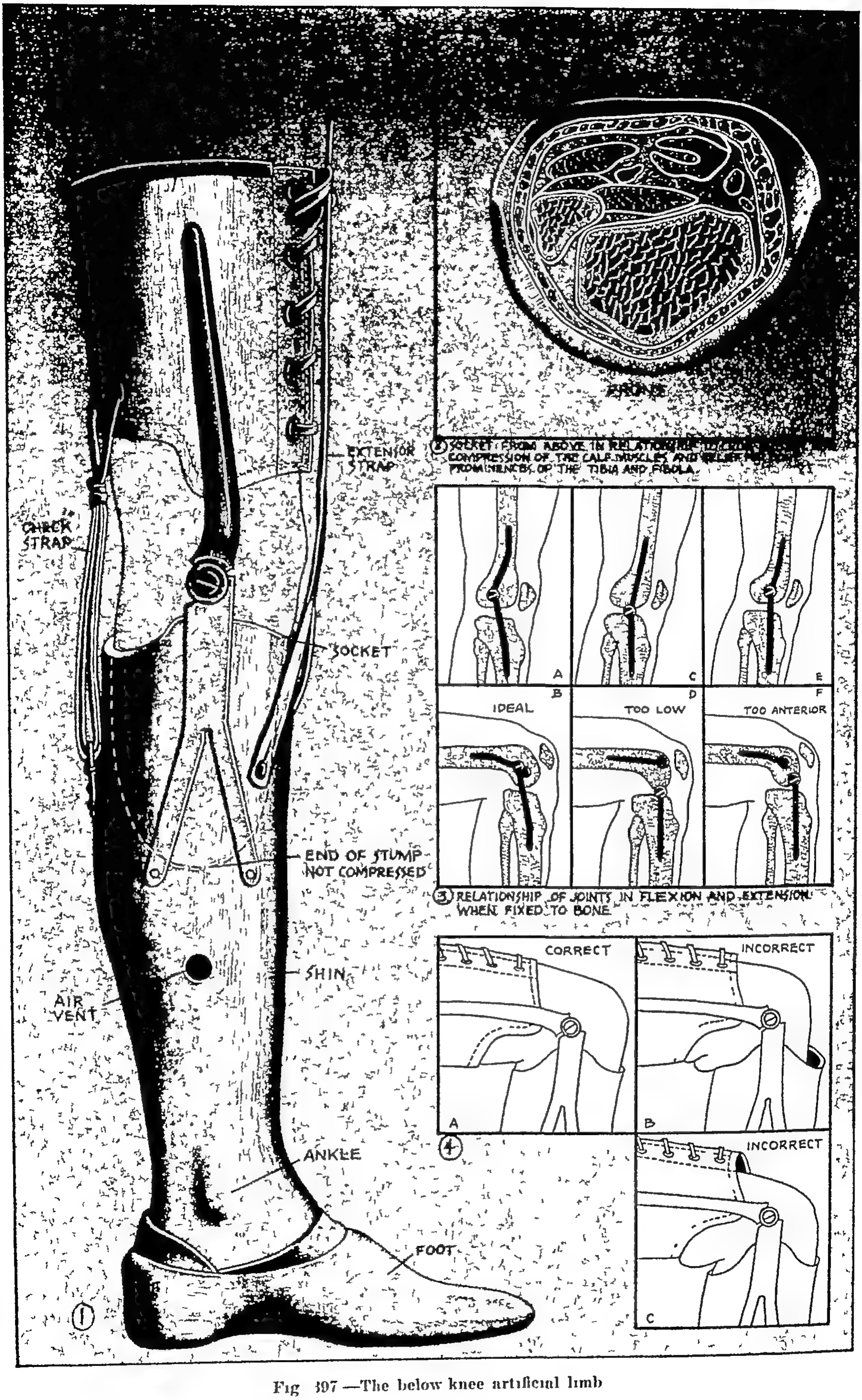


Fig 397 —The below knee artificial limb

pressure and irritation in the perineum, restriction of activity due to the increased height of the limb, greater constriction due to circumferential weight-bearing on the thigh, poorer knee action and a looser fit of the stump within the socket In contrast, the tibial-bearing limb needs but a short thigh corset and eliminates the encumbrance of the prosthesis about the upper thigh and perineum, allows a snugger fit of the stump in the prosthesis, and gives the patient greater walking comfort The tibial-bearing prosthesis is preferred by most American limb fitters, while the ischial-bearing is the most popular among the British and certain Continental limb fitters I feel that ischial-bearing is not necessary in a perfectly normal, well-healed amputation stump which has no undue scarring or evidence of circulatory disturbance But I do consider it indicated as a therapeutic measure in cases in which the scar is not completely sound, in which there is excessive scarring or an abnormal circulatory condition, or where there is pain which is relieved by decreasing the pressure on the weight-bearing surfaces below the knee It is contraindicated when there are painful scars in the region of the ischial tuberosity, or in those instances where flexion deformities of the hip exist and make the mechanical difficulties of constructing the prosthesis too great I have used a complete ischial-bearing limb without a socket below the knee in cases of marked static circulatory congestion, with or without the presence of chronic infectious eczema, in which all attempts at local treatment and physiotherapy have failed The stump is wrapped with an elastic bandage for protection and reduction of swelling, and the patient is allowed to walk Improvement will usually be noted after a week or so and is apparently on the basis of the lessening of circulatory impairment through active use of the extremity When the stump has returned to normal, the patient is fitted with a standard below-knee socket and allowed partial weight-bearing upon the tibial flare In addition to noting the improvement in these stumps, it is gratifying to observe the psychic effect of ambulation upon all who have had their activity curtailed or, at best, limited by the use of crutches

The Standard Below-Knee Prosthesis

The standard below-knee prosthesis is designed for weight-bearing upon the expanding flare of the upper end of the tibia The socket lies within the shin piece and its upper border is constructed to act as a supporting base for the tibial expansion The artificial limb consists of the foot, the ankle joint, the shin piece with socket, the knee hinges, the thigh corset, the back check strap, and the pelvic belt with extensor or supporting strap

The standard artificial *foot* and *ankle* assembly are used

The *shin* is a hollow shell made of wood, metal, fiber, or plastic, which is shaped to resemble the normal limb Into its distal end is fitted the ankle assembly In the event that metal or plastic is used, the ankle base is formed as an integral part of the shin piece, when wood or fiber is employed, a separate wooden ankle base is fixed to the end of the shell At its open upper end lies the socket In the wooden limb this is a unit with the shin piece, which has been shaped to receive the stump, in the metal, fiber, or plastic limb, where it is not possible to create a socket from the main structure of the shell, a separate socket of leather or plastic is fixed into the upper end of the hollow by bolts, screws, or bonding materials At some point below the end of the stump an air vent is placed to prevent overheating of the tissues Since there is no essential difference in the weight of the limb when different types of materials are used, the choice is directed by personal preference or occupational demand

The *socket* is designed to accommodate the stump It extends proximally as far as the upper end of the tibial tubercle on the anterior and posterior aspects,

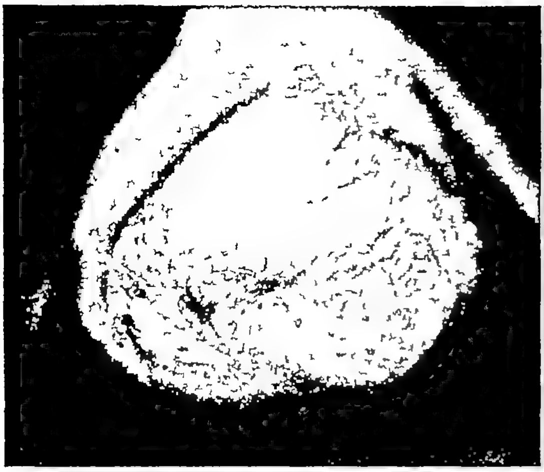
and slightly higher on the lateral and medial at the points where the knee hinges are fastened Its distal end is just below the end of the stump and is not closed, but opens directly into the hollow of the shin piece so that there will be no possibility of pressure upon the stump end As viewed from above, the cross section is roughly triangular in shape The anterior two-thirds are formed to follow the solid, unyielding bony contours of the stump, while the posterior portion is flattened so that the soft tissues of the calf will be compressed sufficiently to prevent the stump from falling within the socket Overcompression in this region may create sufficient pressure to cause serious interference with return flow of venous blood and may, as a consequence, result in swelling and edema of the stump The socket is fashioned to fit snugly about the principal weight-bearing area, the anterior two-thirds of the tibia immediately below the flare of the condyles, so that it will act as a supporting base, and about the patellar tendon when weight is borne in that region, as is the case occasionally It is relieved about those areas which do not tolerate pressure well, namely, the tibial tubercle, the tibial crest (especially at its distal end), the flare of the tibial condyles adjacent to the tubercle, the head of the fibula, and at the level of the fibular neck where the sensitive peroneal nerve passes (About the head of the fibula and the tibial tubercle the skin is thin and subject to decubitus, and painful bursa are often formed in response to pressure) The lower portion of the socket is fitted without compression and serves only to keep the lower end of the stump from being loose and moving too greatly within the shin piece Although the fibula is retained whenever possible to prevent rotation by giving the stump an irregular rather than a circular form, it must be removed occasionally, as in the short below-knee stump In those instances the socket is fitted snugly about the lateral flare of the tibial condyle and some weight is borne there

The *knee hinges* are placed at the sides of the knee joint and are attached to the thigh corset above and to the shin piece below They are not installed as a substitute for the knee joint, but only as an articulation between corset and shin piece which will allow free movement of the existing normal joint It must be appreciated that they are hinges which have a single motion, rotation about a fixed point, and that they are called upon to allow the movement of the prosthesis to be correlated with that of the stump, a member activated by a mobile joint which combines rotation with gliding movement Because of the gliding motion there is no fixed point of rotation within the joint As the tibia passes across the distal surface of the femur during the first part of flexion and the last part of extension, there is some rotation, but the gliding motion is predominant, as it rounds the small posterior aspect of the condyles, the action is chiefly one of rotation Thus the point which can most nearly be defined as the center of rotation is the region of the attachments of the collateral ligaments within the area of the epicondyles In order that the prosthesis can move in approximately the same arc as the stump and thus be comfortably and efficiently controlled by it, the center of rotation of the hinges should overlay that of the joint as nearly as possible If it is too low, the stump is pulled downward in the socket during flexion, if too high, the stump tends to be drawn upward out of the socket, if it is placed too far posteriorly, the stump is forced backward, and if too far anteriorly, there is a tendency for it to be pulled forward during extension

There is some controversy as to the best method of allocating the hinges Some first determine the anatomic center of rotation and set the hinges accordingly, others arbitrarily place them in relation to the socket In the first method, when the bony contours are clearly defined, as in the individual of average weight, the limb maker can ascertain the center of rotation by (1) identifying the surface landmark, the prominence of the femoral epicondyles where the collateral liga-

ments find their attachments, or by (2) defining the femoral condyles and determining the junction of their anterior two-thirds with their posterior one-third. When this means is used, some measure one-half to three-quarters of an inch above the joint line, depending upon the height of the patient, and set the center of rotation at that level, others note the mid-point of the patella, and place it at that height. This last will prove inaccurate if the patella rides high. When the individual is heavy and the bony structures cannot be readily identified, the limb maker can place a finger on either side of the joint in the region of the attachment of the collateral ligaments and, as the amputee flexes and extends the stump, observe at what exact point there is the least variation. In the second method, when the hinges are placed in relation to the socket, the exact location depends upon the limb maker. Usually the distal attachment is fixed at the junction of the anterior three-quarters with the posterior one-quarter of the socket, at the exact center of the anteroposterior diameter, or just within the anterior one-half, the uprights of the hinges are set in the thigh corset at a point slightly posterior to the fixation of the distal attachments to the socket, and the whole hinge is arranged so that the center of rotation is a bit higher than that of the normal joint. In my opinion, the first method is far more sound, for aligning the hinges in relation to the socket does not take into account the differences in individuals, nor the fact that the shrinkage (atrophy) of the calf muscles or loss or addition of weight may alter the relation of the stump to the hinge.

The *thigh corset* serves to fix the prosthesis to the stump and, in addition, usually supports a small fraction of the superincumbent weight. The upright arms of the knee hinges are riveted to it and should be placed with care: if they are fixed too far posteriorly, the stump will be forced away from the anterior supporting border of the socket during flexion, and its fleshy posterior portion will be crowded out over the upper rim of the back of the socket where it will be pinched and will interfere with the full range of motion, if they lie too far forward on the thigh corset, the stump will be drawn backward in the corset during flexion and will press upon its lower posterior rim. The corset is made of leather and is split down the front where it is laced with a leather thong. A leather tongue is used to prevent pinching of the skin by the lacings. In most adults the corset is approximately eight inches long (two-thirds of the length of the thigh). Its lower border should lie one inch above the patella anteriorly and several inches higher posteriorly to allow for flexion of the knee. The posterior inferior margin is usually slit in several places for a distance of about three-quarters of an inch so that no sharp restricting band will be present to interfere with circulation in the popliteal region. In the occasional case, the thigh corset alone is used to maintain the limb. In that event it is fitted very snugly and grasps the thigh strongly just above the patella. Usually, however, a *pelvic belt* is employed as an additional means of support for the below-knee limb. It is made of webbing and passes around the pelvis between the iliac crests and the trochanters. From it is suspended the *extensor strap* which is fixed to the shin piece, and the terminus of which may be either Y-type or T-type. The Y-strap branches immediately above the patella and passes on either side of that structure to be attached on the anterolateral aspect and on the anteromedial aspect of the upper end of the shin at a point three or four inches below the rim of the socket. It is made of elastic webbing and not only serves to hold the limb to the stump but also aids in extension of the knee. It is particularly valuable for amputees who are learning to walk and for those who have inadequate quadriceps power. The T-strap consists of a longitudinal piece of elastic webbing at the end of which is a strip of leather which passes transversely across the thigh immediately above the patella. The transverse strap is fixed to the two uprights



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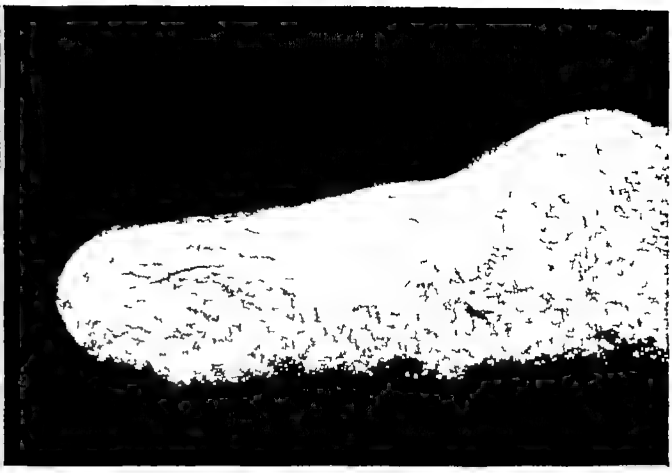

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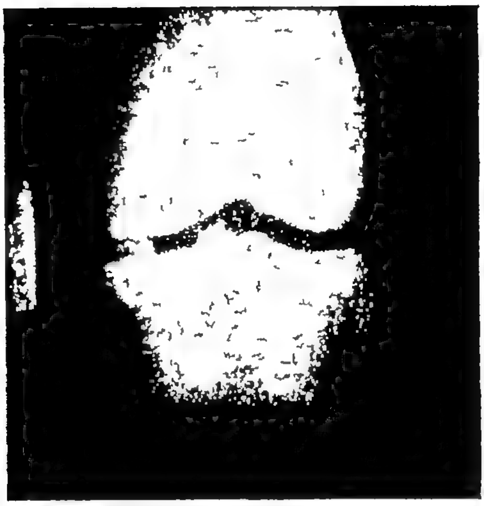

403

Fig 402 —X-ray of a short below knee stump In amputation at this level, or proximal to it, the fibula must be removed if satisfactory fitting is to be obtained In such a stump, weight may be borne on the lateral flare of the tibia to some extent

Fig 403 —X-ray of a very short below knee stump At this level the fibula must always be removed, special fitting is always necessary, and hamstring section is required to allow the stump to fit within the socket

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Fig 398 —Terminal view of an ideal below knee stump Note the short, well healed suture line falling immediately behind the bone, and the normal texture of the skin (Walter Reed General Hospital Neg No 4696-1)

Fig 399 —Side view of the same stump The rounded contour of the stump resulted from the beveling of the tibial crest and the section of the fibula one and one half inches above the end of the tibia (Walter Reed General Hospital Neg No 4696 3)

Fig 400 —Lateral x-ray of a satisfactory below knee stump showing the beveling of the distal end of the tibial crest The fibula is shortened more than necessary in this case

Fig 401 —Anteroposterior x ray of a below-knee stump with bowleg Such a situation is difficult for the limb maker, for the socket must be constructed to fit the stump, while the limb itself, which cannot satisfactorily be made bowlegged, must be placed to fall straight in the usual manner

of the knee hinges, and although it does not aid in extension of the knee, it does provide additional anchorage for the limb and has the effect of making the limb feel lighter

In **checking the below-knee prosthesis for proper fit** a definite routine should be established

1 The patient should first be observed while walking No limp should be present, the foot should not be toed in or out, and no abnormal twist to the gait should be present This last indicates the fact that the mechanical knee joints are not running true, i e, parallel to each other in the sagittal plane

BELOW-KNEE PROSTHESES

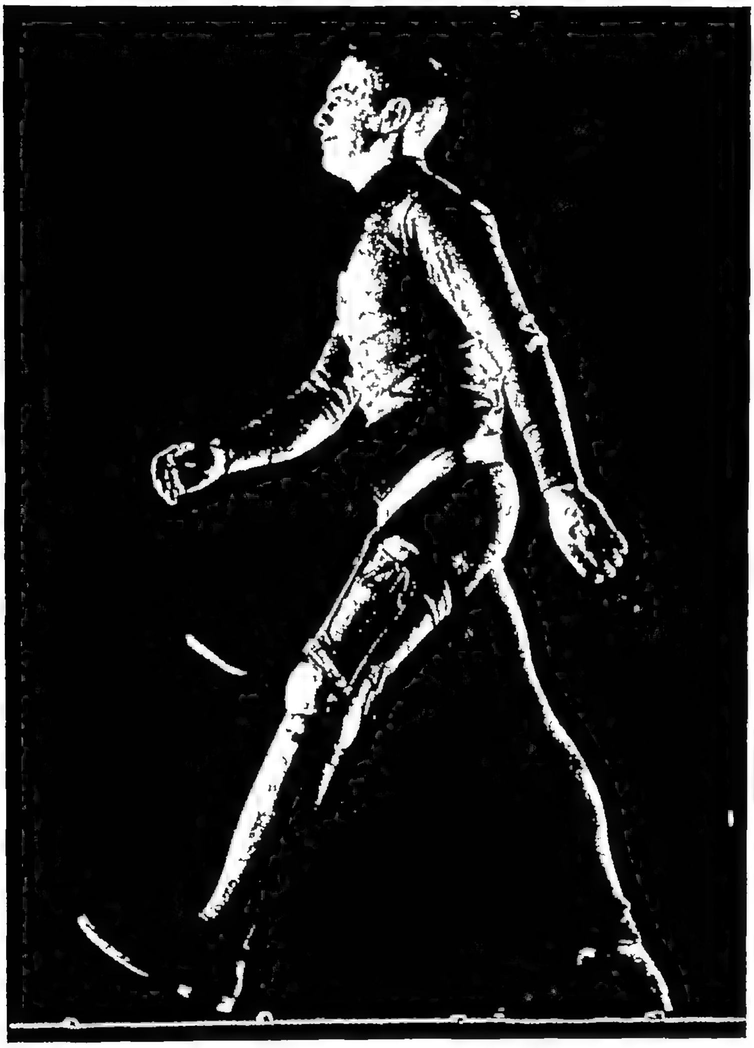

Fig 404 —The standard below knee limb in walking Note the agility of gait, the fact that the pelvic belt rides below the iliac crests, that the extensor strap is of the "T" type, that the check strap in back of the knee is tightened as the knee passes into extension, and that a leather flap is attached to the cross piece of the T strap to prevent clothing from dropping within the socket (Courtesy of Gjon Mili)

2 The examiner should next place the patient in the standing position and check the following points

a The *length of the limb* The extremities should be of equal length as indicated by the levels of the anterior-superior spines If there is a discrepancy it may lie in the length of the shin piece (which should be comparable to that

of the normal shin), or in unequal wear on the heels, or it may be due to the fit of the stump within the socket or the thigh corset. If the socket is too large, the stump will slip down too far within it, and the extremity will be shorter than the normal; if the socket is too small, if too many stump socks are worn, or if the thigh corset is laced more tightly than necessary, the stump will not rest as far within the socket as it should and the limb will appear to be overlong.

b. The *fit of the thigh corset.* The thigh corset should be approximately two-thirds of the length of the thigh. A longer one may impinge upon the delicate structures of the perineum above or upon the popliteal region below, impairing venous return and hindering the flexion of the knee joint; a shorter one must be laced too tightly in order to be firm. The side arms of the hinges should not press into the soft tissues of the thigh, and should be so placed that both corset and socket fit well in flexion. The circumferential fit of the corset is highly important, for it influences the manner in which the stump rests within the socket.

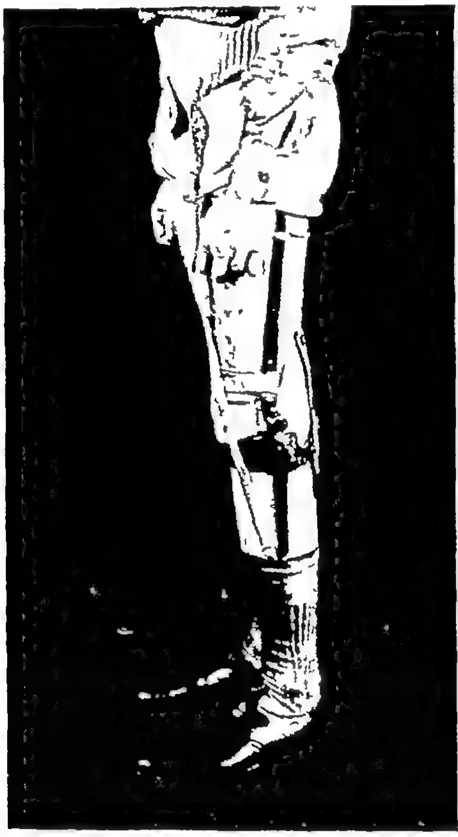

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Fig. 405.—The ischial bearing prosthesis for below the knee. The thigh corset is extended well upward so that weight can be partially borne on the tuberosity of the ischium and the gluteal shelf. This patient is wearing a "Y" type of extensor strap which is fixed below to the shin. He is also wearing a cross strap immediately above the patella to minimize the piston action of the stump during gait. (Walter Reed General Hospital Neg. No. 4010 A4.)

Fig. 406.—A standard below knee prosthesis demonstrating two common faults: the pelvic belt is worn above the crest of the ilium on the right side and presses inward on the right flank, and weight is being borne on the lower border of the patella.

It is dependent upon two factors, the actual circumference of the corset in relation to the thigh, and the manner in which it is laced. Both should be checked carefully. The corset may have become too small due to increase in muscle development or general body weight, or it may have become too large because of quadriceps atrophy or weight loss; the lacings may be drawn too tightly if the corset is short or if it is donned when the patient is in the sitting position with

the muscles of the thigh lax (it should always be laced while he is standing), not infrequently it may purposely be laced tightly because of tenderness in the stump below

c The *socket*

(1) The weight should be distributed throughout the weight-bearing surface with no unusual pressure on any one spot

(2) The stump should rest within the socket so that a finger's width (3/8 of an inch) lies between the anterior rim and the patella (Weight-bearing on the patella itself is tolerated very poorly) If the stump is too deep within the socket, it is due to defective fitting of the socket itself or shrinkage of the stump, if it rides too high out of the socket, the socket is too small in relation to the size of the stump, or the patient is wearing too many stump socks

(3) The posterior aspect is checked to insure that there is no undue pressure on the fibula and that there is no bunching of soft tissues over the posterior rim The height of the posterior rim should be equal to that of the anterior or nearly so

(4) The number of stump socks is counted to determine whether the stump is shrinking or is stationary in size

(5) The alignment of the socket within the shin piece is checked, for, if this is incorrect, the upper portion of the stump will press against one side of the proximal part of the socket, and the end of the stump will rub against the opposite side of the distal part of the socket

3 The limb should then be checked with the patient in the sitting position The fit of the corset should be good, the side arms of the knee joint should lie comfortably without pressure on the underlying soft tissues, the socket should fit normally with no undue pressure in the popliteal region, the knee should come comfortably to the 90 degree position, and the stump should not rise out of the socket

Compression of certain areas because of improper fitting of the prosthesis may impair the return flow of venous blood and result in swelling, edema, cyanosis, or other circulatory disturbances When any one of these conditions is present, the following points should be checked as the most likely sources of trouble

1 Constriction of the thigh by the sharp posterior-inferior border of the thigh corset This can usually be remedied by cutting the corset somewhat higher or by placing a number of longitudinal slips across its distal posterior rim

2 Compression of the great vessels caused by undue pressure of the posterior aspect of the socket upon the gastrocnemius muscle This muscle transmits the pressure to the great vessels which pass between its two heads and lie between it and the soleus It is usually necessary to refit the socket in order that this pressure may be relieved

3 Compression of the distal end of the stump This may be the result of any one of three factors

a The lower portion of the socket may be too small In that event, reaming out of that part of the socket to enlarge its circumference will rectify the matter

b The socket may not be snug enough in the weight-bearing area and as a result the stump may be dropping too far down within the narrowed portion of the socket, or the patient may be wearing a number of stump socks in an effort to achieve a better fit The addition of leather liners within the upper portion of the socket will decrease its circumference and allow the stump to rest correctly within it without the use of too many stump socks It should be remembered that these liners should extend roughly no farther than the point at which

the tibial tubercle merges into the tibial crest (two to three inches), for if they are within the distal portion of the socket they will cause compression of the end of the stump in the same way as if the socket were constructed too small

c Improper alignment of the socket within the shin piece may be causing the distal end of the stump to press against the side of the socket Realignment will bring relief from this pressure

The Ischial-Bearing Below-Knee Prosthesis

In the ischial-bearing prosthesis for below-knee amputation, the thigh corset is high, extending upward to form a supporting base for the ischial tuberosity which is to bear the greater part of the weight In every other respect it is the same as the standard tibial-bearing limb During the limb-check the same routine is observed as that for the standard limb, but in addition the proximal portion of the thigh corset is inspected to insure that it is sufficiently relieved in the region of the perineum to avoid compression in that area, and that it fits snugly under the ischial tuberosity

The Complete Ischial-Bearing Below-Knee Prosthesis.

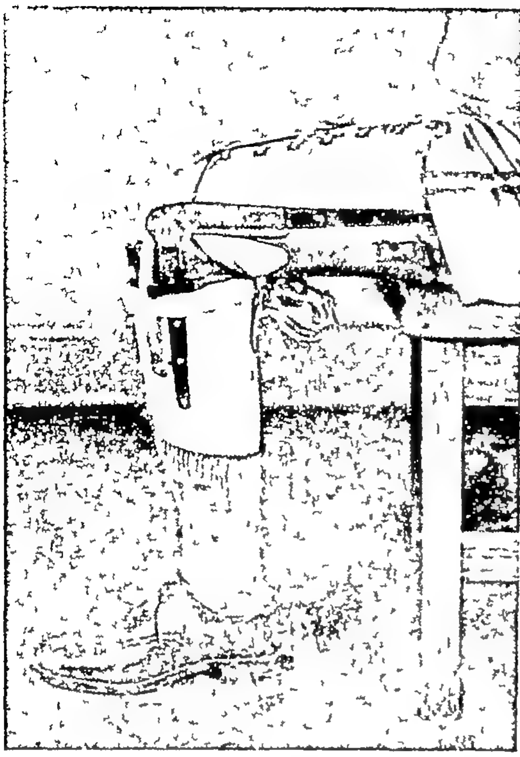
The complete ischial-bearing below-knee prosthesis is a specific therapeutic device to relieve the below-knee stump and tibial region of any compression In it the shin piece contains no socket but is merely lined with a soft material to keep the stump from bruising as it comes in contact with the shell The actual socket may be formed by the thigh corset which is then reinforced with steel to form a seat for the ischial tuberosity, or it may be constructed within a thigh piece in the manner described under the discussion of the above-knee prosthesis The stump should lie loosely within the shin piece and the socket should not compress the thigh, especially in the region of the perineum, but should fit firmly under the ischial tuberosity

Prostheses for Long Below-Knee Stumps

When amputation is performed below the ideal level in the leg, that is, distal to the mid-point of the tibia, circulation is poor and the likelihood of tension on the scars is great because of the excessive piston action The additional length is of no advantage as a lever arm at that level but is a very definite disadvantage from the prosthetic standpoint, for though the standard tibial-bearing below-knee prosthesis can be used, it loses its symmetry when the socket is adjusted to the long stump It will be remembered that the socket must extend approximately an inch below the end of the stump, it can readily be seen that with each added inch of length the limb becomes more unsightly, for the shin piece must be roughly cylindrical (in order to contain the socket) to within a few inches above the ankle joint, and then cut down sharply to accommodate that assembly The appearance created is much like that of an inverted milk bottle and is responsible for the nickname of "milk bottle leg which is applied to this limb

Prostheses for the Short Below-Knee Stumps

The fitting of the short below-knee stump has always been a difficult problem because of the tendency of the stump to fall out of the socket of the artificial limb In practice this is most likely to occur during rapid extension from the flexed position, during forced flexion as in walking uphill, or during the sudden flexing of the stump which occurs as the patient attempts to keep from losing his balance In the latter two instances the hamstring tendons, as they contract, tend to press against the posterior rim of the socket and lift the leg out of it As might be expected, the shorter the stump the more pronounced is this difficulty. In order to determine in the individual case what length of



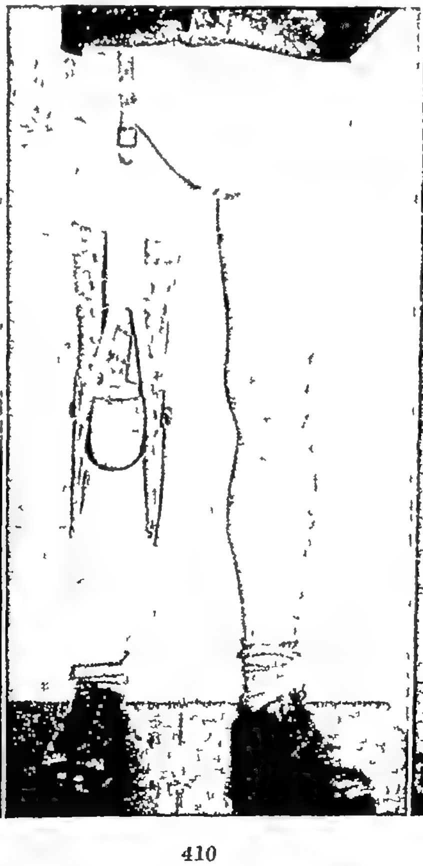
407

408

Fig 407 —Very short below knee stump fitted with a standard prosthesis following hamstring section (Courtesy of H C Blair and H D Morris)

Fig 408 —The slip socket prosthesis This is designed so that the socket moves with the stump, and slips up and down to some extent in the shin piece In this manner, the piston action occurs between the shin piece and the socket, and the socket does not tend to slip off of the short stump during flexion and extension (Courtesy Veterans Administration.)

409



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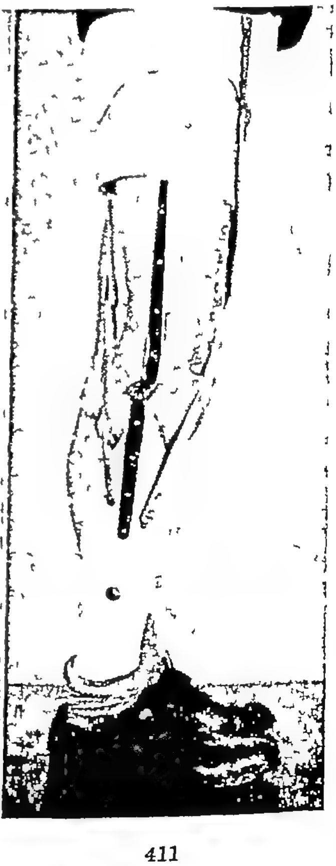


411

Figs 409, 410 and 411 —The bent knee stump and the bent knee prosthesis, front and side views (Walter Reed General Hospital Neg No 4182 2, 3, 4)

stump can normally be contained within the socket, the following simple clinical test may be performed the hand is placed behind the extended stump with the index finger lying transversely about one inch below the articular joint line (that finger represents the posterior rim of the socket) and as the knee is flexed it is noted at what point the finger is forced off of the stump If it is retained when the knee reaches 90 degrees flexion, it is assumed that the patient will be able to maintain the stump within the limb without further surgery, if it is forced from the stump before the knee has flexed to 90 degrees, surgical section of the hamstring muscles, as described by Blair and Morris, should be undertaken to increase the extent to which the stump will sink into the socket

The short below-knee stump may be fitted in several ways

1 The standard below-knee limb may be used, but special care must be taken to insure that the posterior rim of the socket is high, and that notches are cut in it to permit room for the hamstring tendons If the bone level is at the flare of the tibial condyles, the stump will withstand partial end-bearing In that event the weight may be received upon a net woven of leather thongs and covered with suitable padding which is placed across the bottom of the socket

2 In exceptional cases a "slip socket" may be substituted for the conventional socket It is designed to move with the stump rather than with the shin, and when it is used piston motion takes place between socket and shin rather than between socket and stump

3 A bent-knee prosthesis may be used when neither of the previous two alternatives is practical It is particularly useful in the presence of a flexion contracture The extremity is placed within the limb with the knee at 90 degrees flexion so that the weight is borne upon the anterior surface of the knee joint and the tibia With the knee thus fixed in the flexed position by the corset, normal knee action is precluded and a substitute must be provided The limb used is actually the standard end-bearing prosthesis such as is used in knee disarticulation and amputation about the distal end of the femur, and is constructed in the manner described below in the discussion on the knee-bearing limb It employs the standard foot and ankle, and a shin piece without socket which is connected by side knee hinges to a leather corset The corset varies from the standard in that it is necessarily longer and is open on the posterior aspect near the distal end to accommodate the end of the stump This type of fitting is one of the most satisfactory weight-bearing limbs for the lower extremity, but it is limited to men for cosmetic reasons

The Standard Artificial Knee Joints

The knee joint is the articulation between the thigh and the leg, and it is through its motion that the lower part of the extremity is positioned Normally, the quadriceps and the hamstring muscles of the thigh, which have their insertions in the upper end of the tibia, control this joint motion and help to maintain the body in balance above it the quadriceps assists and controls the natural pendulum swing which extends the leg, and checks against extreme flexion, the hamstring muscles assist and control the pendulum swing in the flexion of the joint and act as a stop against overextension The range of motion is from 180 degrees to 70 degrees, walking requiring 110 degrees flexion, sitting 90 degrees, and squatting necessitating 70 degrees Throughout the full range of motion the quadriceps and the hamstring muscles hold the extremity in tight control and make possible the biphasic extension which is present in normal gait, i e, the joint is extended as the heel strikes the ground, flexes as the sole of the foot contacts the floor, and extends again levering the body forward to reach

full extension as the extremity is at right angles to the ground and the body weight is directly over the foot This series of movements in conjunction with the muscular control exerted on the pendulum action makes for a smooth even gait

In the artificial knee joints which have proved practical, activation and simple control are satisfactorily supplied, but, as yet, no practical and durable substitute has been found for the strong quadriceps power which makes possible the biphasic extension As a result, the prosthetic knee affords only a single phase of extension (the knee is straight throughout the entire period of support), and gait with its use is less smooth than the normal

There are two devices which are standard substitutes for this joint, the lateral knee hinges, and the knee assembly with knee bolt Each is suited to a different set of circumstances The lateral knee hinges were designed primarily for the long thigh stump for they require little space longitudinally and depend upon a long lever arm for motivation and stability They consist of two metal hinges, one on the lateral and one on the medial side of the limb with the distal flanges fixed to the shin piece and the proximal fixed to the thigh corset They are placed so that their centers of rotation correspond in height to that of the normal joint and lie just behind the center of gravity The motion of the hinge joint is mechanically simple flexion and extension are brought about by the pendulum swing impelled by the movements of the thigh, just as in the normal, an extensor strap of the terminal "Y" type, which is fastened to the anterior aspects of the pelvic belt and the shin, assists these motions and helps to check against extreme flexion, a back check strap takes the place of the normal hamstring muscles in preventing overextension In this type of joint there is no means of retarding the forward swing of the shin, and it snaps through rapidly, causing a rather awkward gait It does, however, have the distinct advantage of stability, for the long lever arm controls it against "jackknifing," or sudden flexion, during the weight-bearing period The knee bolt type of joint was devised for the limbs adapted to amputation proximal to the junction of the lower and middle thirds of the thigh where there is no long lever arm to activate a hinge joint and where a little more stability is necessary It is more complex than the hinge type, deriving its motion from the action of an extensor mechanism within the assembly, and needs more room between the end of the stump and the end of the thigh piece The many bolt-type knee joints commercially available vary as to internal mechanism and manner of mounting, but all follow the same general principle of a gliding bolt within a hollow sleeve, and all have the following four essential parts

1 The knee *bolt* is a cylindrical or tapered rod which passes through a transverse hole in the distal portion of the thigh piece and is fixed at either end to the shin piece Its gliding surface may be smooth or may contain ball or Oilite bearings It forms the center of rotation of the artificial joint and should be placed at the level of that of the normal joint For the sake of stability during weight-bearing, it should lie just behind the center of gravity for if it is located too far anteriorly, the knee will buckle, especially when weight is first placed on the heel If it is placed too far posteriorly, the joint will be stable, but the limb will be lengthened during flexion, the amputee will then have either to lift the pelvis or overflex the thigh in order for the foot to clear the ground during the forward motion of the leg, and the gait will be slow and ungainly

2 The *extensor mechanism* used may be one of several types The most common is an extensor strap of elastic webbing which is attached to the anterior

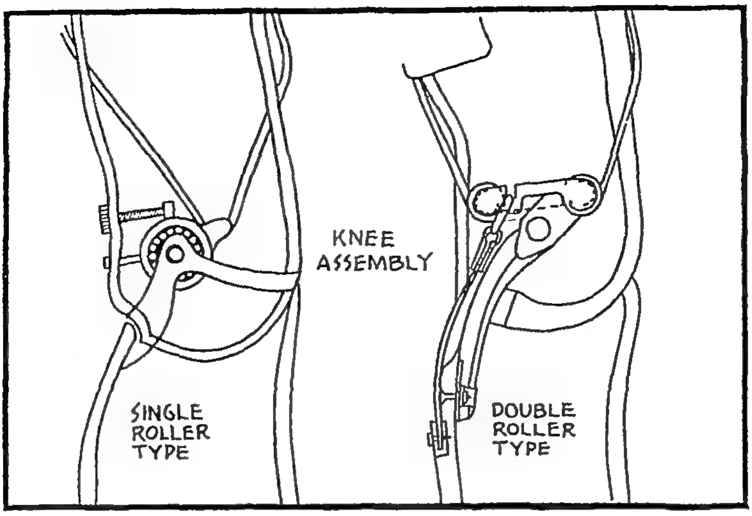
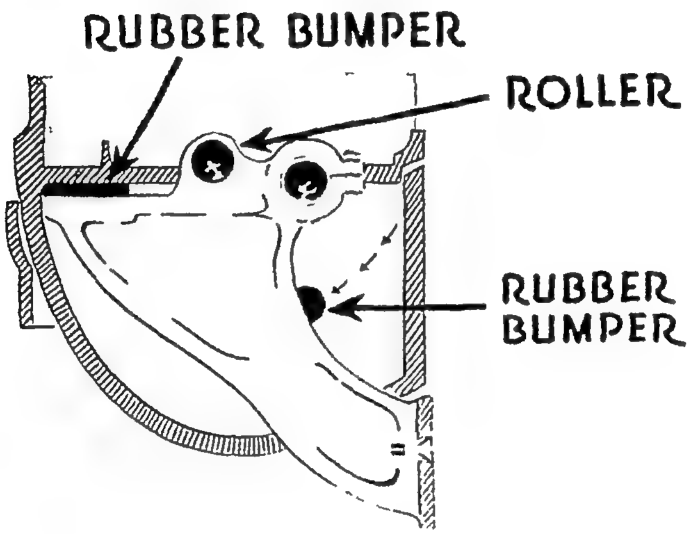
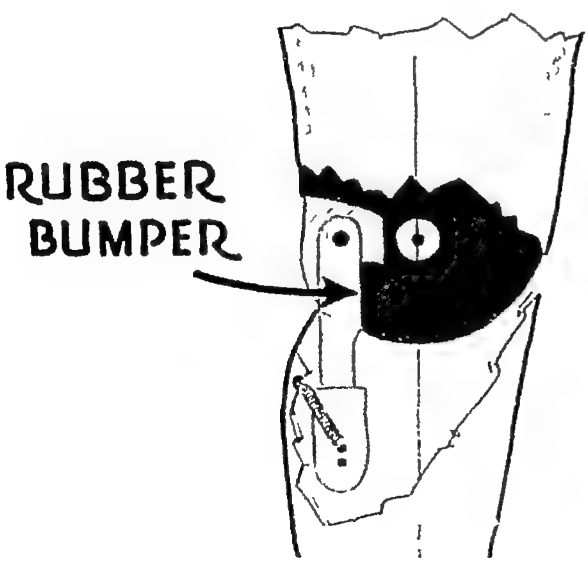


Fig 412—Single and double roller types





Figs 413 and 414—Anterior and posterior knee bumpers which prevent hyperextension and excessive flexion, respectively

aspect of the thigh piece or the pelvic belt (the latter being less desirable for it tends to pull the belt forward and increase lumbar lordosis) and which extends down the outside of the limb to be threaded through a hole at the level of the joint mechanism (As it approaches the hole, leather is used for the strap instead of webbing) It then passes through the internal mechanism of the joint, usually of the single or double roller type, and out through a hole in the posterior aspect of the thigh shell to follow upward along the outside of the thigh piece and be fixed to the back of the pelvic belt A second type of extensor mechanism is an extensor strap which passes from the anterior aspect of the thigh piece, or belt, over the rounded end of the knee assembly to be attached to the posterior aspect of the shin piece below the knee Yet another type produces extension by simple spring action In all, the tension can be regulated to suit the gait of the individual It should be of a degree to draw the leg forward readily but should not be so strong that the shin will kick forward in a sudden awkward jerk

3 The *knee brake* is a friction device designed to prevent the free swing of the shin on the thigh piece Without it the shin is not closely enough controlled by the stump, as the thigh is flexed, the shin piece swings back in flexion sharply and does not then start forward as quickly as it should for it must actually wait for the impulsion of pendulum action, this causes the amputee to overflex the thigh in an effort to hurry the leg forward, and then to extend it suddenly to bring the heel against the ground and stabilize the free-swinging knee joint in extension as he enters the period of weight-bearing The degree of friction which the knee brake affords can be regulated by increasing or decreasing the tension on it, and thus the correct amount of stump control can be achieved The exact amount of friction desirable varies with the individual gait, but it is generally conceded that it should be that which will allow the shin piece to fall slowly into flexion as the limb is held in the horizontal position To adjust the brake for very minimal friction is unwise, for it causes the amputee to overflex the thigh in order to place the leg forward, and the resultant gait is both awkward and tiresome To tighten the friction mechanism excessively, as those who walk rapidly are prone to do, is mechanically undesirable for it places undue strain upon the internal knee mechanism and requires exceptional strength and control from the stump

4 The *extensor check* is the device which prevents the knee from extending beyond 180 degrees It can be a short posterior check strap extending between thigh piece and shin piece, or it can be a bumper arrangement on the anterior aspect where the upper rim of the shin piece contacts the thigh piece

One of the principal difficulties in the use of the knee bolt type of joint has been its tendency toward sudden "jackknifing" during weight-bearing This is particularly marked during the first phase when the heel strikes the ground, and is due to the lack of a long, strong controlling stump There have been a number of attempts made to create a device which will overcome this difficulty, but thus far each has met with objections upon one ground or another The oldest of these mechanisms consisted of a rod extending upward from the foot, which locked the knee when weight was placed on the heel and released it when weight passed toward the toes Another type was a simple lever controlled by gravity, which fixed the knee in extension when the thigh was placed in forward flexion and released it as the thigh went into extension More recent attempts, which are as yet in the developmental stages, include various types of hydraulic mechanisms to accomplish similar tasks There is no question that stability of the knee is desirable The trouble in the past has been that these mechanisms were too complicated and that they required frequent repair which was difficult to obtain A second objection and one which research is trying to overcome has

been the fact that the knee joint with such a mechanism will lock while the patient is going downstairs as weight is placed on the artificial heel, and that the knee will not then flex so that he can take the step below with the other foot, he must, as a result, go through a series of single steps to descend

Prostheses for Knee-Bearing Amputations

Knee-bearing amputations are those performed through the knee joint or just proximal to that level They result in a long stump with a broad distal bony flare suitable for end-bearing They require a limb which provides a substitute for foot, ankle, shin, and knee, and which is constructed to support direct weight-bearing upon the end of the stump From the prosthetic standpoint the bent-knee stump of the short below-knee amputation can be classified with these knee-bearing stumps, for it too presents a long end-bearing lever arm and demands artificial knee action In the knee-bearing limb the standard foot and ankle are employed The shin piece is a hollow shell which is formed to simulate the normal shin except that its upper end is somewhat wider in order that it may receive the broad flare of the long thigh element The hinge type of knee joint is used and its center of rotation is placed approximately one-half inch behind the mid-point of the anteroposterior diameter of the shin and thigh pieces The upright arms are fixed to the thigh corset and are extended almost to its proximal border to act as reinforcement The thigh corset, or socket, is made of molded leather and extends from the end of the stump to within two or three inches of the perineum The bottom of the socket is rounded in shape to conform to the end of the stump, and the weight-bearing surface is covered with a pad of felt or other cushioning material to make it more comfortable Additional pads may be utilized to make minor adjustments in the length of the limb The anterior aspect of the socket is opened to within an inch or two of the stump end and is secured by leather lacings This opening allows the stump to be placed within the socket, and the lacings afford a means of adjusting the tension of the corset upon the thigh Materials other than leather have been used upon occasion but have not proved very satisfactory because of bulk and because they are not readily adjustable as to size When the prosthesis is adapted to the bent-knee stump, the lower posterior aspect of the corset is opened and the short stump protrudes through it slightly The limb is suspended from a pelvic belt by the extensor strap on the anterior aspect and by a piece of elastic webbing on the posterior The extensor strap is similar to the "Y" strap of the below-knee prosthesis and is used to extend the leg on the thigh In rare instances, it will be necessary to fix the limb to the body by means of a conventional pelvic band and hip joint

When the knee-bearing limb is first worn, the thigh corset is usually laced tightly so that the stump lies away from the bottom of the socket and the weight is carried on the sides of the thigh Then the laces are loosened gradually so that the stump will become accustomed to the pressure of the body weight Most amputees bear some small portion of the weight on the sides of the thigh even after years of wearing the limb

The knee-bearing limb has both advantages and disadvantages It is well controlled by a long powerful lever arm and being end-bearing does not require the high thigh corset which is likely to cause discomfort by pressure in the perineum (This last factor is particularly important to the double amputee) On the other hand there is not room to accommodate a knee joint equipped with a friction mechanism without distorting the proportion of the extremity, and the shin swings freely upon the thigh piece making gait somewhat awkward In

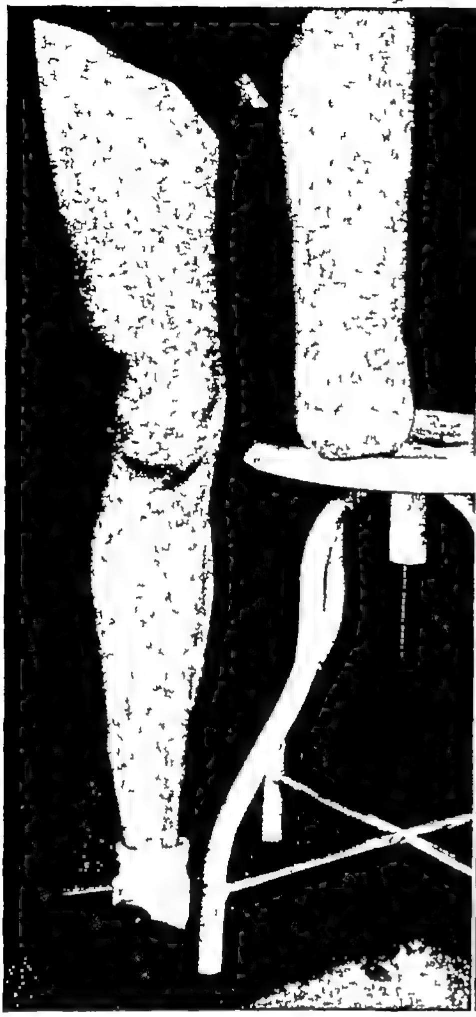


Fig 415

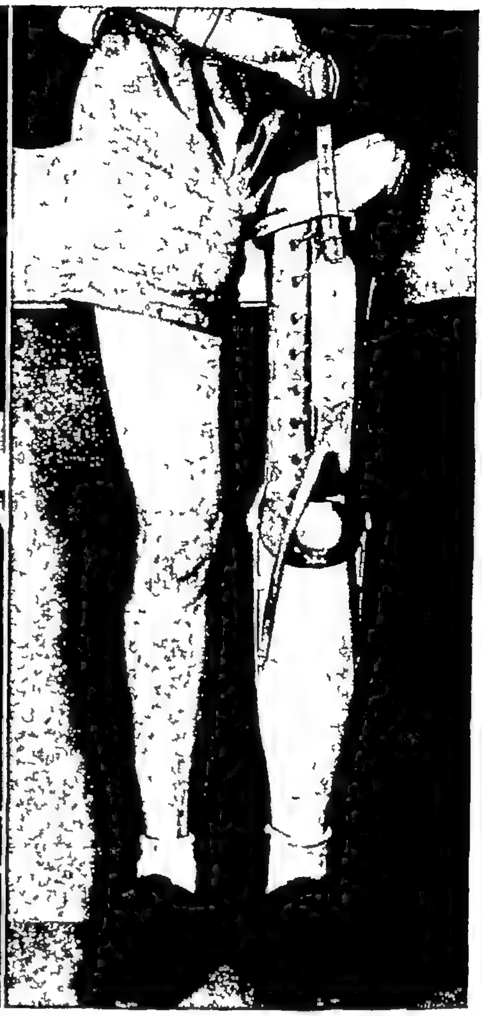


Fig 416

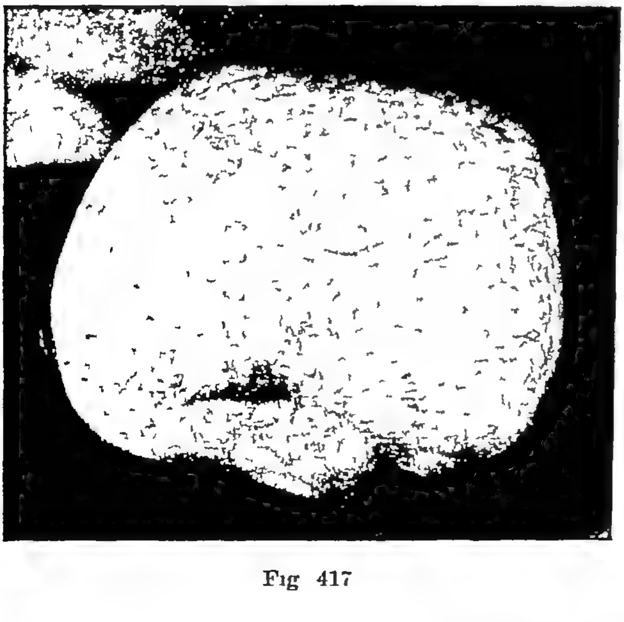


Fig 417

Figs 415 and 416 —The stump, anterior and terminal views (Courtesy of R H Alldredge England General Hospital Neg No SA 788, SA 801)

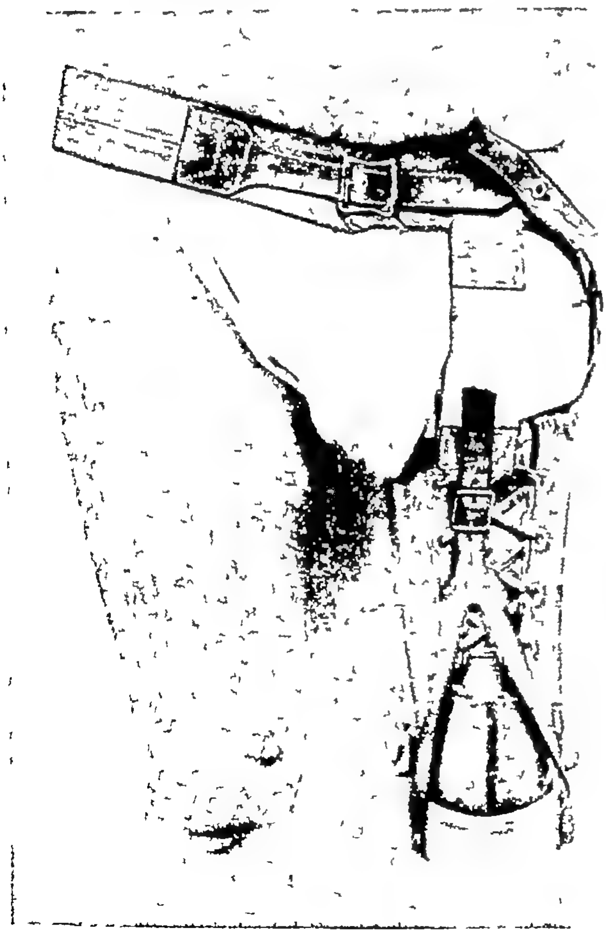
Fig 417 —The prosthesis The lower end of the socket is expanded to accommodate the broad flare of the femoral condyles (Courtesy of R H Alldredge England General Hospital Neg No SA 789)

418

419

Fig 418—Side view of a typical rounded epicondylar amputation stump (Walter Reed General Hospital Neg No 4551-4)

Fig 419—Terminal view of a rounded epicondylar stump of a 67 year old laborer Note the broad weight bearing surface Note also the slight redundancy at the posterior aspect of the stump, left intentionally because of the diminished elasticity of the skin in an older individual



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421

Figs 420 and 421—Front and side views of the conventional prosthesis used for rounded epicondylar, Kirk, Callander, and Gritti Stokes amputations, here adapted to a rounded epicondylar stump The socket tapers gradually with no expanded flare at its distal end, the width at the knee joint approximates the normal, and the cuplike end of the socket is not disturbed by the anterior lacing which starts several inches above the stump end The pelvic belt and suspension straps may be made of webbing rather than leather and metal as shown here, or this same type of belt with a metal hip joint may be used

addition, the socket necessarily extends below the stump and makes a slight discrepancy between the length of the artificial thigh and the opposite normal thigh, which may occasionally be noted when the amputee is in the sitting position, this difficulty, however, can usually be overcome by the skilled limb maker as he constructs the prosthesis, so that little or no difference is apparent

Prostheses for Amputation of the Thigh

The stump resulting from amputation through the continuity of the femur is not capable of end-bearing and is therefore planned for proximal-bearing upon the tuberosity of the ischium It is a relatively short stump and for that reason affords less power for controlling and stabilizing the prosthesis than stumps derived from amputation at a lower level, also, that very shortness plus the fact that it has a single bone and is tapering in shape makes for difficulty in maintaining the artificial limb and keeping it from rotation

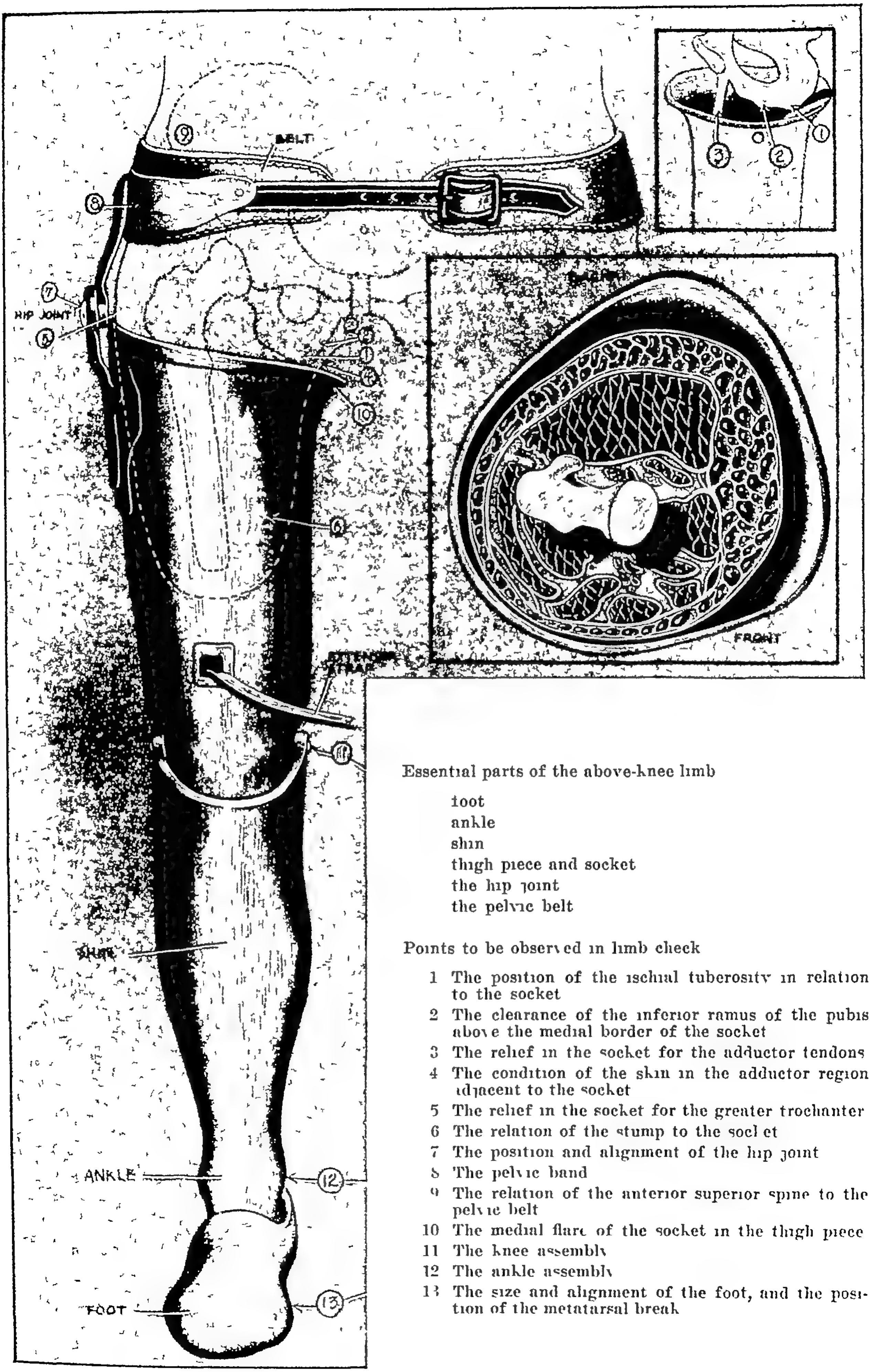
Several decades ago the prostheses for thigh amputations, or the above-knee limbs as they are more commonly called, did little to compensate for these peculiarities At that time the standard limb was suspended by shoulder straps and the amputee lifted the limb from the ground by a shrug of the shoulder and swung it forward by a shifting of the trunk Such a manner of suspension merely held the limb to the body but did nothing to furnish stability against rotation, and such an indirect means of control resulted in a gait which was a far cry from the normal In more recent years these inadequacies have been largely overcome by employing for suspension a pelvic belt to which the limb is firmly fixed by a strong hinge Suspension thus provided affords strength and stability against rotation and allows direct control of the limb by the muscles of the hip and the stump itself The hinge serves an additional purpose in that it guides the course of the prosthesis as it is flexed and extended With this pelvic type of suspension considerable muscle exertion and training in the use of the limb are required, but the result is gratifying for the upper part of the body is left free from restriction, the stump itself is kept fit by use, and the unsightly shrug of the shoulder and shambling gait are avoided The hip joint and pelvic belt are now a part of the standard above-knee limb as it is used in the United States, and the shoulder straps have been almost entirely relegated to use as supplementary suspenders in such cases as (1) the elderly or debilitated patient who lacks the muscle strength for complete stump control, (2) the patient whose occupation requires much rapid movement of the limb so that stump control alone would be too exhausting, (3) the patient who lacks the will or the perseverance to learn the proper use of the limb, and (4) the amputee whose stump is so short that it tends to pull out of the socket during flexion and extension of the limb In this last instance the shrug of the shoulder can be used to assist the stump in positioning the limb, and the straps provide additional means of holding the prosthesis to the body

The Standard Above-Knee Limb

The standard above-knee limb is composed of foot, ankle, shin, knee assembly, thigh piece containing the socket for ischial-bearing, hip joint, pelvic belt, and, occasionally, shoulder straps

The conventional *foot* and *ankle* are employed

The *shin* piece is a hollow shell of wood, fiber, plastic, or metal, fashioned to conform to the lines of the normal leg Its sides extend to the level of the knee joint so that it can be fixed to the ends of the knee bolt, and its anterior and posterior borders are cut slightly lower so as not to interfere with the joint motion



Essential parts of the above-knee limb

- foot
- ankle
- shin
- thigh piece and socket
- the hip joint
- the pelvic belt

Points to be observed in limb check

1. The position of the ischial tuberosity in relation to the socket
2. The clearance of the inferior ramus of the pubis above the medial border of the socket
3. The relief in the socket for the adductor tendons
4. The condition of the skin in the adductor region adjacent to the socket
5. The relief in the socket for the greater trochanter
6. The relation of the stump to the socket
7. The position and alignment of the hip joint
8. The pelvic band
9. The relation of the anterior superior spine to the pelvic belt
10. The medial flare of the socket in the thigh piece
11. The knee assembly
12. The ankle assembly
13. The size and alignment of the foot, and the position of the metatarsal break

Fig. 422.—The above knee artificial limb

The *standard knee assembly with knee bolt* is used As was stated above, there are many variations of this type of joint, any one of which may be satisfactory The manner in which they are installed in the limb depends upon the one used some are fitted directly into the thigh piece, others are fixed into a knee block which is adapted to the end of that member

The *thigh piece* like the shin may be made of wood, fiber, plastic, or metal It is a hollow shell which follows the contours of the normal thigh down to the level of the knee joint, at which point it narrows sharply in order that it may lie within the extended sides of the shin piece without making the knee excessively bulky It has an opening on the anterior aspect, just above the joint, through which the extensor strap passes, and the distal flange of the hip joint is secured on its lateral side In its distal end, well below the stump, lies the knee assembly and within its open upper end rests the socket

The *socket* extends from well up under the ischial tuberosity to approximately two inches below the stump end In the wooden limb it is actually part of the thigh piece which is carved to fit the contours of the stump, and it is painted on the inside with moisture-proof varnish so that it provides a slick surface In this way, as piston action occurs during walking, the friction between stump and socket is minimized and excessive tension on the terminal scar is avoided In the fiber limb the upper end of the thigh piece is molded in the form of the socket and is lined with an insert of leather In the metal or plastic limb a separate socket is made and fitted into the upper end of the thigh piece

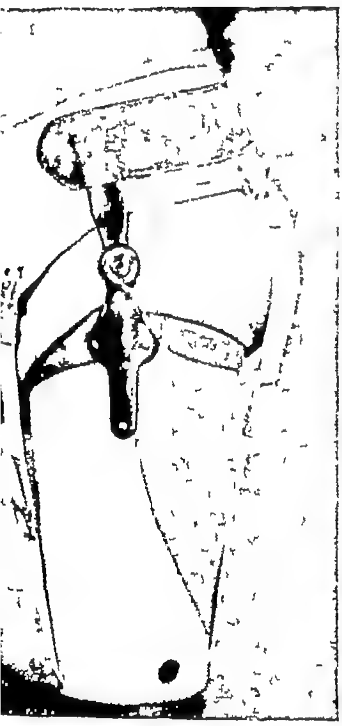
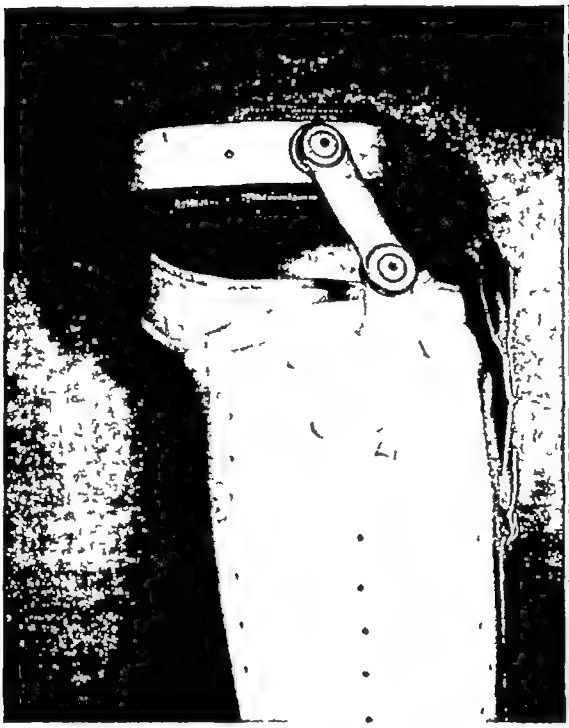
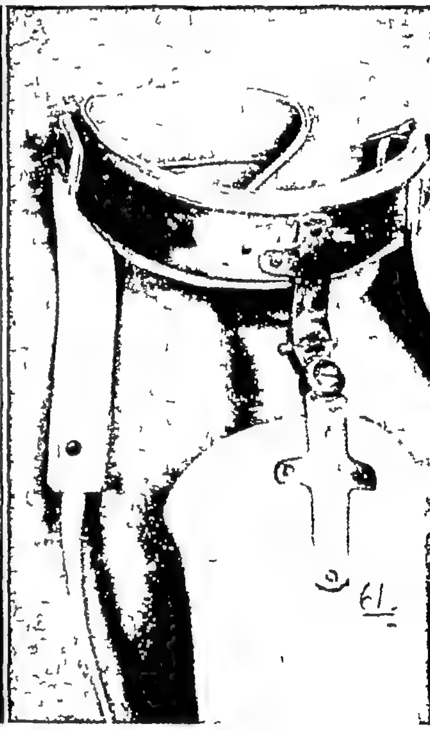
In cross section, as the limb is observed from above, the upper border of the socket is roughly triangular in shape the base of the triangle is represented by the medial aspect, and the apex is that point immediately lateral to the greater trochanter Below its upper margin, the socket in cross section is seen to become more circular in shape as it conforms to the rounded contour of the nonweight-bearing portion of the stump The socket is slightly higher on the lateral aspect, where it extends to the level of the greater trochanter, than it is on the medial, where it rises to a point just below the perineum Thus, when viewed from the front or the back, it slopes slightly In the socket fitted to the very short thigh stump this slope will be more exaggerated, nearly paralleling the ilioinguinal (Poupart's) ligament, for the lateral aspect is then extended on the thigh as high as it is possible without interfering with the flexion of the hip

The upper portion of the socket is so formed that the weight-bearing points are snugly fitted and firmly supported, while the sensitive structures are carefully relieved A broad flare on the medial portion of the posterior aspect forms a close-fitting "seat" for the ischial tuberosity, the principal weight-bearing point, while a similar rest, slightly less flaring, affords support for the gluteus maximus which shares a small part of the burden The anterior portion of the socket is fitted in close contact with the anterior aspect of the stump for, though this region bears practically no weight, it does furnish counterpressure to help maintain the ischial tuberosity in position Care is taken, however, to avoid any compression of the femoral vessels The entire rim of the socket is gently rounded, for there is necessarily some small fraction of weight borne on the skin throughout the circumference of the stump with the exception of that in the region over the greater trochanter and the site of the adductor tendons The socket is carefully relieved over the bony prominence of the greater trochanter to avoid chafing and bruising, and again where the adductor tendons cross the anterior-medial border of the socket, as they arise from the symphysis and inferior ramus of the pubis and pass downward to insert on the medial border of the femur Great care is necessary in the fitting of the medial aspect

of the socket, for any pressure or irritation upon that side of the stump or upon the perineal region will result in discomfort and a compensatory abduction stance and gait When weight is placed upon the stump, it should fit within the socket so that there is clearance of one fingerbreadth between the inferior ramus of the pubis or ischium and the medial rim of the socket, the adductor tendons, as was noted, should be absolutely free from pressure, the skin should not be pinched, and the expanding border of the socket, where it is relieved for the sake of the adductor tendons, should not protrude enough to impinge upon the sensitive structures of the perineum

The socket below the weight-bearing area is fitted in gentle contact with the stump so that there will be neither undue play nor undue pressure It extends at least one and one-half inches below the end of the stump to keep the stump from possible bruising contact with the thigh shell

ARTIFICIAL HIP JOINTS

423 424 425

Fig 423—The standard simple hinge joint

Fig 424—The double hinge joint (Courtesy of Veterans Administration)

Fig 425—The double hinge joint allowing motion in two planes (Courtesy of Veterans Administration)

The socket must fit the stump and not the stump the socket This is an inflexible rule Only too often have unusual or deformed stumps been put in sockets which have not been particularly adapted for them, and limb maker and amputee have tried "to make it do " When the stump is flexed or abducted and is placed in the usual vertical socket, the patient may walk well at first, but will soon become subject to muscle strain and fatigue For such a stump the socket should be specially designed with some flexion, though not necessarily as much as is present in the stump itself It must be remembered that many flexion contractures, particularly those in stumps approaching the ideal length, may be gradually corrected by the use of the limb, and that constant adjustment must be made upon the socket and the pelvic band as this deformity lessens

The *hip joint* is the metal hinge which fixes the limb to the pelvic harness, keeps it from rotating, and allows free motion of the normal hip joint. Its distal flange is riveted to the lateral side of the thigh piece, and its proximal to the steel band which is part of the pelvic belt. The proximal attachment should be curved to fit the contours of the hip as closely as is possible without causing chafing or rubbing. The hinge is placed in relation to the normal joint. The anatomic hip joint is generally conceded to be at a point immediately anterior to and at the level of the anterior-superior border of the greater trochanter. (This will, of course, vary with coxa vara, coxa valga, and flexion contracture of the hip.) Experience has proved that the mechanical hip joint should be placed so that its center of rotation will lie slightly below that of the normal joint. A further and most important detail in the allocation of the mechanical hip joint is that it is placed in slight medial deviation (internal rotation) in relation to the sagittal plane of the body as it rests in the neutral standing position. This is based on sound mechanical principles of gait. It will be noted that the pelvis on the side of the trailing leg is rotated posteriorly just before take-off and that the leg has already swung forward before the pelvis is again in the neutral position; it will also be noted that the forward swing of the leg is not in an arc, as is that of the pelvis, but is along a straight line parallel with the line of forward progression, i.e., the shortest distance or the most direct line between the point where the individual is standing and the point toward which he is traveling. Thus it is evident that the thigh during its forward progress lies in internal rotation in relation to the pelvis. By fixing the mechanical hip joint in medial deviation upon the pelvic band, the same principle is mechanically achieved, and the prosthesis lies in internal rotation and swings forward parallel to the line of progression rather than following the arc of the pelvis in an abduction gait. The degree of medial deviation necessarily depends on the height of the individual, the breadth of the pelvis, and the length of the average step taken.

When the stump is short and slightly flexed, it is not sufficiently strong to guide the course of the limb. The motion of the pelvis must then be used to substitute for the action of the stump. By placing the hip joint more anteriorly and in greater internal rotation, the plane of motion of the hinge is at marked variance with the line of progression and binds when the leg is brought forward so that the motion of the pelvis is transmitted to the prosthesis.

The *pelvic belt* is made of leather, thoroughly padded, and passes around the body to buckle in the front. Fixed to it on the side on which the limb is attached is a steel piece (pelvic band) which is approximately one and one-half inches in width and extends from a point just anterior to the anterior superior spine backward around the body to a position roughly equivalent to the posterior superior iliac spine. It is to the pelvic band that the upright of the hinge joint is secured. This portion of the belt should lie as low as possible in the groove between the iliac crest and the greater trochanter, and the steel band should be bent to follow the lines of the body. Special care should be taken in contouring this band around the anterior superior iliac spine to insure against pressure on that bony prominence. When the belt is fastened comfortably, it should fit the body snugly throughout, but especially in the region where the band is mounted, for any shifting or play in the fit of this member will throw the whole limb out of alignment, and internal rotation, external rotation, adduction or abduction of the prosthesis on the stump may occur.

If *shoulder suspension* is deemed necessary, either one or two straps may be used. In the first instance a single broad band of webbing is attached to the posterior aspect of the thigh piece, passes upward over the opposite shoulder

and then follows downward across the front of the body to be joined to the extensor strap on the anterior aspect of the limb When two straps are used, both are fixed to the posterior aspect of the thigh piece, then one passes upward over the left shoulder and one over the right, and they join on the anterior aspect of the limb to be attached to the extensor strap To prevent their lateral displacement a cross strap joins one to the other on the back at the level of the upper border of the scapula and a circular band of webbing passes around the body at the level of the lower rib cage

THE STANDARD ABOVE-KNEE LIMB

426 427 428

Fig 426 —Front view of the stump and artificial limb
Fig 427 —Side view of the artificial limb
Fig 428 —Side view of the artificial limb with the hip flexed to show how the portion of the extensor strap which passes up the back of the thigh to the pelvic belt maintains the relationship between the prosthesis and the stump

The following routine is suggested for the above-knee limb check

The patient is first observed while walking Any of the following defects in the gait are noted and the pertinent points in the limb are checked as possible causative factors

1 Awkward gait with overflexing of the thigh may be due to excessive length of the limb or insufficient friction on the knee brake

a The limb may be too long because

(1) the over-all length of the limb is too great because of an error in measurement or construction

(2) The stump is not resting down within the socket This may be traced to the wearing of too many stump socks or to the fact that the socket itself is too small This last may be the result of a gain in general body weight or muscle development since the time of fitting or may be due to a fault in the original

fitting The observer should make a note to check the manner in which the stump rests in the socket when the patient is in the standing position

(3) The knee hinge has been placed too far posteriorly If this is the case, the limb will be longer than the normal when the knee is flexed and the amputee will have to overflex the hip awkwardly in order to clear the ground in the forward swing of the leg

(4) The instep bumper is too large When this is true, the foot is forced into excessive plantar flexion so that the toe drops down and tends to drag on the ground during the forward swing of the shin, and the amputee must, as in the situation above, overflex the thigh in order to lift the foot clear This fault in the size of the instep bumper is also responsible for the often-noted short and jerky step, for the last "take-off" phase of gait cannot be accomplished when the foot is thus locked against dorsiflexion

b There may be insufficient tension on the knee brake When this is the case, the amputee must either overflex the thigh in an attempt to swing the shin and foot through quickly enough, or he must wait for pendulum action to bring the member forward In the first instance the gait is awkward and the knee is brought too high, in the second the timing of the gait is off and the step of the artificial extremity is slower than that of the normal

2 Abduction gait may be due to any one of several factors

a An overlong limb In many instances, the amputee whose limb is too long will, rather than overflex the thigh, swing the entire extremity in an outward arc in order that the foot may clear the ground

b The fit of the socket in the perineal region Pinching of the skin, pressure on the adductor tendons, or any other irritation of the structures on the medial aspect of the thigh will result in abduction during stance or gait This is a purely compensatory reaction to relieve the painful pressure areas Occasionally a socket will be found which has a broad medial flare which causes pressure in the perineum In this instance the pressure point may act as a fulcrum so that when the body weight falls on the stump, that member is levered laterally These patients complain of pain in the perineum and over the lateral aspect of the terminal end of the stump and have an abduction gait Furthermore, if the medial flare of the socket is too great, it may injure the delicate structures of the perineum Bilateral thigh amputees must often wear a genital suspensory for this reason

c The fit of the pelvic belt When the limb is fitted, it is properly aligned and then fixed securely in that alignment to the steel band portion of the pelvic belt It is essential, therefore, that the belt be snugly fastened in the proper position at this time, and that the pelvic band be contoured to fit closely to the body so that no alteration in its position will occur If the fixation of the limb to this proximal harness has been done when either of these elements was not properly fitted, the alignment of the limb will be thrown off when any adjustment is made upon them, in like manner, a decided increase or decrease in general body weight may alter the degree of tension on the belt and thus change the point at which the limb is fixed or the angle at which it lies If, after final fitting, the belt is for any reason fastened more tightly, the upper border of the pelvic band will be drawn inward, the hip joint will be angled outward, and abduction gait will result

d Incorrect amount of medial deviation of the hip joint If the angle of placement of this joint is miscalculated, the limb may swing outward in its forward motion rather than paralleling the line of progression

e The amputee's fear of "knee buckling" Not infrequently the amputee will not trust the stability of the artificial knee joint and so will fear to flex the limb, lest it buckle on him when he attempts to extend it and place weight upon it In such a case he will walk stiff-legged, swinging the limb in abduction gait rather than flexing the knee joint and directing the limb forward in a straight line The knee bolt should be checked for proper placement, and if this is found to be correct, the patient should receive further training in walking, with stress upon his feeling of security

3 Adduction gait, like abduction, may result when the pelvic belt is too loose or is improperly fitted, or when the alignment of the hip joint is incorrect

4 Irregular gait with the pelvis dropping on the side of the prosthetic limb during the weight-bearing period occurs when the artificial member is too short This may be due to improper length measurement at the time of fitting but is more likely to result from the stump dropping too far within the socket because of stump shrinkage, loss of weight, or the fact that the socket was constructed too large When the patient is later placed in the standing position, the length of the limb should be checked and the fit of the stump within the socket carefully noted

5 If the shin kicks forward too rapidly, causing an uneven, jerky gait, the tension of the extensor strap may be too strong, or the knee brake may not be adjusted for sufficient friction It is not unusual for the amputee with the short stump to jerk the limb forward with a quick movement in an effort to compensate for the lack of a strong lever arm Further training in the use of the limb is then indicated, and when the stump is strong enough, the tension on the knee brake may be increased to afford closer stump control

6 If the gait is tedious, with hyperextension of the knee (beyond 180 degrees), the back check strap or anterior knee bumper, whichever is employed, should be checked for improper adjustment

7 If the forefoot slaps down upon the ground, the source of trouble can be traced to the heel bumper This is sometimes mistakenly considered characteristic of amputee gait, but is unnecessary and is due to a too small heel bumper or to one which is not sufficiently firm

8 If the limb seems to twist during the last phase of gait, throwing the amputee off balance, it is probably due to incorrect alignment of the ankle assembly or to too great or too slight a degree of obliquity in the position of the metatarsal break

9 If the gait has a twisted appearance during the swing phase, the shin will usually be found to be lying at a slight angle to, rather than in a direct line with, the thigh piece, due to improper transverse placement of the knee bolt

The patient is next asked to stand Since the fit of the stump within the socket is now to be considered, inquiry is made into the number of stump socks that the patient is wearing This acts as a guide to the amount of shrinkage of the stump Originally, the socket should be constructed to fit properly when one stump sock is worn (One ordinary wool sock will increase the circumference of the stump about one-half inch, while a cotton one will increase it about three-sixteenth of an inch) If at the time of the limb check three or four stump socks are being worn, it is evident that the stump has shrunk until it is no longer adequately fitted by the original socket In that event the socket should be lessened in circumference by the insertion of a leather liner, or if that is not practical, a new socket should be constructed, for an excessive number of socks will crowd the stump until its shape has little or no relation to the shape of the socket If, on the other hand, the amputee has been wearing but one or two

socks, it may be assumed that adjustments of the prosthesis, if any, will be minor, and the limb check is continued with the inspection of the following points

1 The position of the ischial tuberosity in relation to the upper rim of the socket The patient is instructed to place most of his weight upon the opposite leg while the examiner places his finger between the ischial tuberosity and the posterior-medial aspect of the socket As the weight is transferred to the artificial limb, the examiner's finger should be impinged between the tuber ischii and the rim of the socket If this does not occur, the stump is not resting properly in the socket

a It may be falling too far within it If only one stump sock is being worn, the use of an additional one may remedy the situation, if the patient is already wearing two, a leather liner may be placed in the socket to decrease its circumference, if the use of two stump socks and a leather liner will not suffice, a new socket should be made

b The stump may not fit down within the socket far enough This may occur (1) because too many stump socks are being worn or there are too many liners within the socket, (2) because there is swelling in the stump or it has shrunk less than was anticipated by the limb maker, or (3) because the socket was made purposely small so that weight would be borne on the sides of the stump This last manner of fitting is called a "plug fit" and is most undesirable for it places undue pressure on the skin and tension on the terminal scar, and often results in a painful overhanging "roll of flesh" in the adductor region

2 The inferior ramus of the pubis or ischium The normal clearance of one fingerbreadth should be present between these bones and the medial rim of the socket

3 The adductor tendons These structures should be completely free of pressure, the socket being relieved for this purpose

4 The medial aspect of the stump is inspected for pinching or irritation of any kind As was noted above, if the socket has been fitted so that the weight has been borne upon the sides of the stump, a "roll of flesh" in this region may be found to have largely replaced the tuber ischii as the principal point of weight-bearing These tissues, having been subject to continuous pressure, may have become fibrotic, or their circulation may have become impaired, and if they have gone long without attention, ulceration, sebaceous adenitis, and infection may be present The early treatment of this condition consists of removing the limb, allowing the tissues to readjust themselves, and refitting at a later date with greater clearance in this area so that the stump fits down into the socket properly When thoroughly established, this condition must either be tolerated as a painful weight-bearing area or be surgically excised In the latter instance the surgical scar is in an undesirable position where it will frequently be subject to irritation from the artificial limb

5 The relief of the socket lateral to the greater trochanter There should be no evidence of chafing or bruising of the tissues over this bony prominence

6 The socket below the weight-bearing area This portion of the socket should be examined to ascertain that it is properly aligned and is not forcing the stump to lie in flexion, adduction, or abduction It should fit the stump without compression and should extend far enough below the stump end to protect it against bruising

7 The mechanical hip joint should be inspected for breakage for it is under considerable stress Note should also be made of its alignment to ensure that it is not causing the limb to lie in adduction or abduction

8 The pelvic belt is examined to determine that it is resting as it should between the iliac crest and the greater trochanter, and that there is no pressure being exerted upon the anterior superior iliac spine Any change in body weight which affects the comfort and fit of the belt should be noted and alterations in the harness made accordingly, care being taken that the fixation of the hinge to the band is retained in the proper position

9 The length of the artificial limb is next noted It should be such that an imaginary line drawn through both anterior superior iliac spines would be parallel to the ground Concessions in the length of the limb may occasionally be necessary to facilitate clearing the ground with the artificial foot during walking In stumps of normal length, shortening of not more than one-half inch is generally sufficient if the patient has been properly instructed in walking In the short stump where piston action between stump and socket is greater, a little more shortening is sometimes required Much discrepancy between the length of the artificial and the normal limbs is most undesirable for it distorts the general body mechanics and usually leads to the development of arthritic changes in the spine If the limb is too short or too long and it has already been determined that the ischial tuberosity is resting in its normal position in the socket, note should be made to check the relative lengths of the thigh and shin piece when the patient is in the sitting position in order that the discrepancy may be corrected

10 The medial flare of the rim of the socket is inspected to ensure that it does not exert pressure on the delicate structures of the perineum

11 The knee bolt is checked for alignment It should lie far enough behind the center of gravity to ensure stability during extension, but not so far that it makes the limb overlong in flexion, and its transverse position should be such that the shin piece is in a direct line with the thigh piece with no angulation present

12 The ankle assembly is examined for possible wear and the heel and instep bumpers are checked for position and correct size and resilience

13 The artificial foot is compared to the normal for size and shape They should correspond exactly in this respect in order that paired shoes may be purchased The metatarsal break is checked for correct angulation and the condition of the bumper, connecting fabric, and sole cushion are noted

Finally, the patient is asked to assume the sitting position

1 The relative lengths of the shin and thigh piece are compared to those of the opposite extremity If the shin is too long, the prosthetic thigh piece will rise above the normal, if the thigh is too long, the artificial knee will stick out beyond the normal knee

2 The pelvic band and the hip joint are studied Since the proper allocation of the hip joint on pelvic band and thigh piece dictates the position of the prosthesis in the sitting position, errors in positioning may readily be found by noting any internal or external rotation of the artificial limb

3 There should be no pinching of the skin and soft tissues between the anterior lip of the socket and the anterior portion of the pelvic belt

An above-knee limb which is constructed with a suction socket and requires no harness has been used successfully for many years in Germany and recently in a few cases in this country Since it cannot yet be considered a standard limb in the United States, and since its principle radically different from that of the conventional socket, has been experimentally employed at other levels in the lower extremity and occasionally in the upper extremity it will be discussed under a separate heading following this section on the Lower Extremity Prostheses

Prostheses for Amputations About the Hip

The normal hip joint and the muscles which govern it position the lower extremity as a whole. When amputation approaches the level of the lesser trochanter, the function of this joint is nullified, for the short stump which remains is neither long enough nor strong enough to control the artificial limb. When hip disarticulation is performed, joint motion is of course lost and not even the short stump remains to aid in stabilizing the prosthesis. Amputations about the hip must therefore be fitted with an artificial member which can be activated by the movements of the pelvis and trunk in place of the normal hip motion, and which is capable of supporting the entire body weight as it is borne chiefly by the ischial tuberosity and in some measure by the gluteus maximus. This type of prosthesis presents the limb maker with one of his most formidable problems. It is difficult to construct and fit the socket when little or no stump remains to prevent rotation, and the shrinkage of the stump is often rapid once the prosthesis is worn, so that frequent adjustment is necessary to maintain an accurate fit. There are two types of prostheses which may be used, the tilting table prosthesis and the above-knee limb with a special molded socket. In both, the amputee's gait is awkward for, since no strong lever arm is present, the knee and hip joints are locked during walking to promote stability and to allow control by the trunk.

The *tilting table limb* is fitted to the majority of stumps in this region. It is at best a heavy and cumbersome substitute for the missing extremity. It consists of foot, shin, thigh piece, socket, and proximal harness with articulations at ankle, knee, and hip.

The foot, ankle, and shin are conventional in type.

The knee joint in most cases is composed of the standard knee bolt with a locking device. Except in the very rare instance where the hip amputee is able to control artificial knee motion, the knee joint is locked during stance and gait and unlocked only when the patient wishes to sit down. Therefore, the knee assembly is not usually equipped with brake and extensor mechanism.

The thigh piece is a hollow shell, the upper rim of which curves gently upward from the usual level on the medial side to a point opposite the normal site of the greater trochanter on the lateral aspect. On it, placed where it is most conveniently reached by the individual amputee, is the bar which is manipulated through the clothing to lock and unlock the knee joint. Fixed to the anterior aspect and to the posterior are the suspenders which come from the pelvic belt or the shoulder harness. The distal flange of the hip joint hinge is fixed on the lateral border of the thigh piece, and rollers which articulate with the socket for additional fixation and support are attached on the medial side of the anterior and posterior borders. If the amputee appears capable of walking with knee motion, an extensor strap can be arranged and fixed to the proximal harness in the usual manner.

The hip joint is a heavy steel hinge which is fixed above to a steel band which reinforces the socket. The most common type is equipped with a push button on its outer side for locking and unlocking the joint. In spite of its great strength this hinge alone cannot withstand the stress applied to it from above. This fact has led to the construction of a metal track which runs from front to back on the medial portion of the distal aspect of the socket. It is with this track that the rollers on the upper end of the thigh piece are articulated. Although this contrivance bears a large share of the weight, the strain upon the hip joint is great and breakage is frequent.

The socket is made of leather which has been molded upon a plaster replica of the stump and reinforced by heavy steel bands. It must act as a supporting

Fig 429 —Hip disarticulation

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431

Fig 430 —Subtrochanteric amputation
Fig 431 —Amputation through the upper end of the femur

seat for the ischial tuberosity which bears the greater part of the weight, and for the gluteus maximus which carries the remainder of the load. For this reason its medial border should extend toward the midline as far as is possible without creating pressure in the perineal region. Since it is the movement of the pelvis which powers the prosthesis at this level, it is important that the limb grasp that part of the body firmly. Amputation which leaves even the smallest amount of femur has the advantage over hip disarticulation in this respect for it provides a stump with an irregular contour which can be grasped more firmly by the socket and which, to some extent, combats the tendency toward rotation. On the other hand, the short thigh stump is usually flexed to 90 degrees and falls in some abduction and external rotation and the socket must be formed to accommodate this.

The pelvic belt is employed in all cases to hold the socket snugly to the pelvis. It is wide and well padded and passes below the opposite iliac crest. A limited number of amputees will be able to use it for suspension also and do

PROSTHESES FOR AMPUTATIONS ABOUT THE HIP

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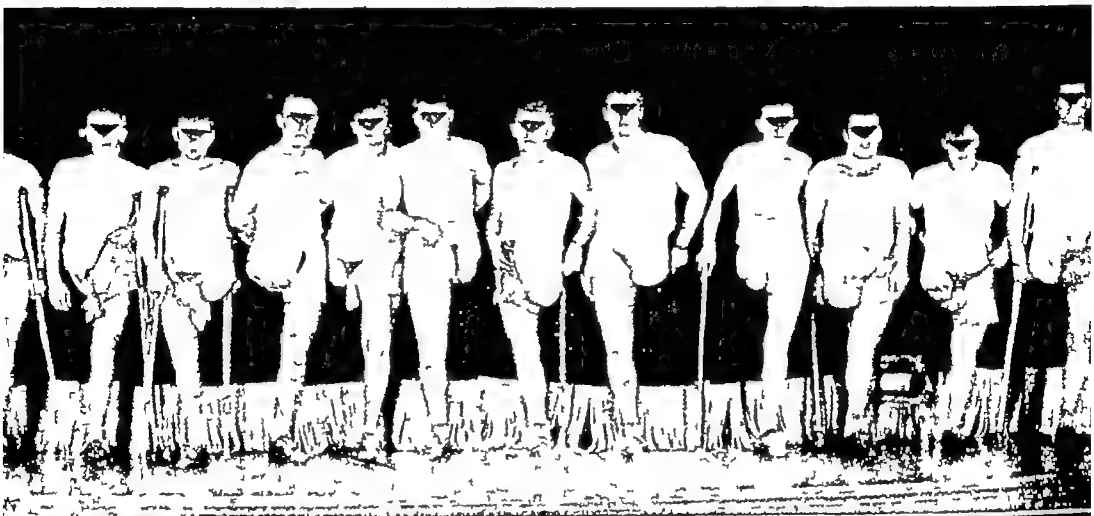

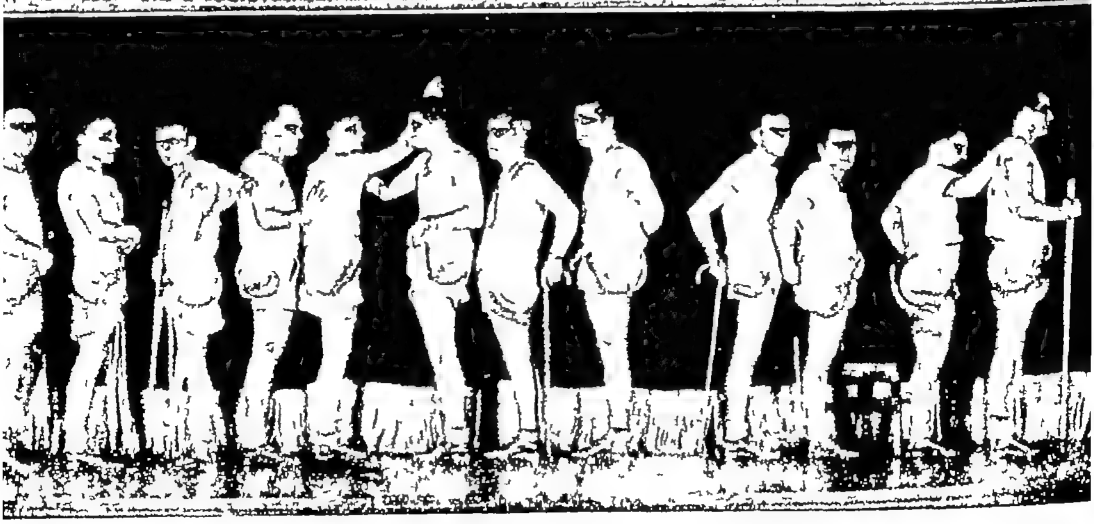

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Figs. 432 and 433—Front and side views of a group of amputations about the hip, showing the variations in stump configuration. (Walter Reed General Hospital Neg. No. 4649 1, 4.)

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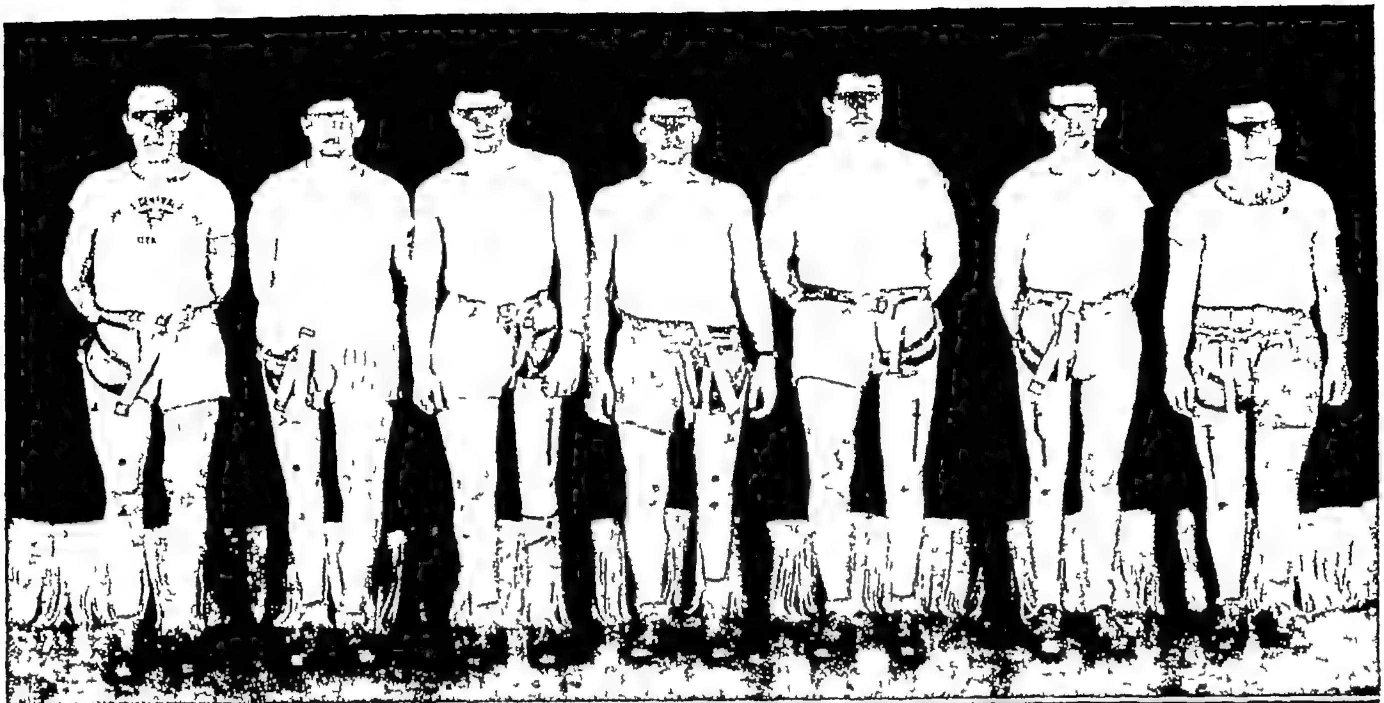

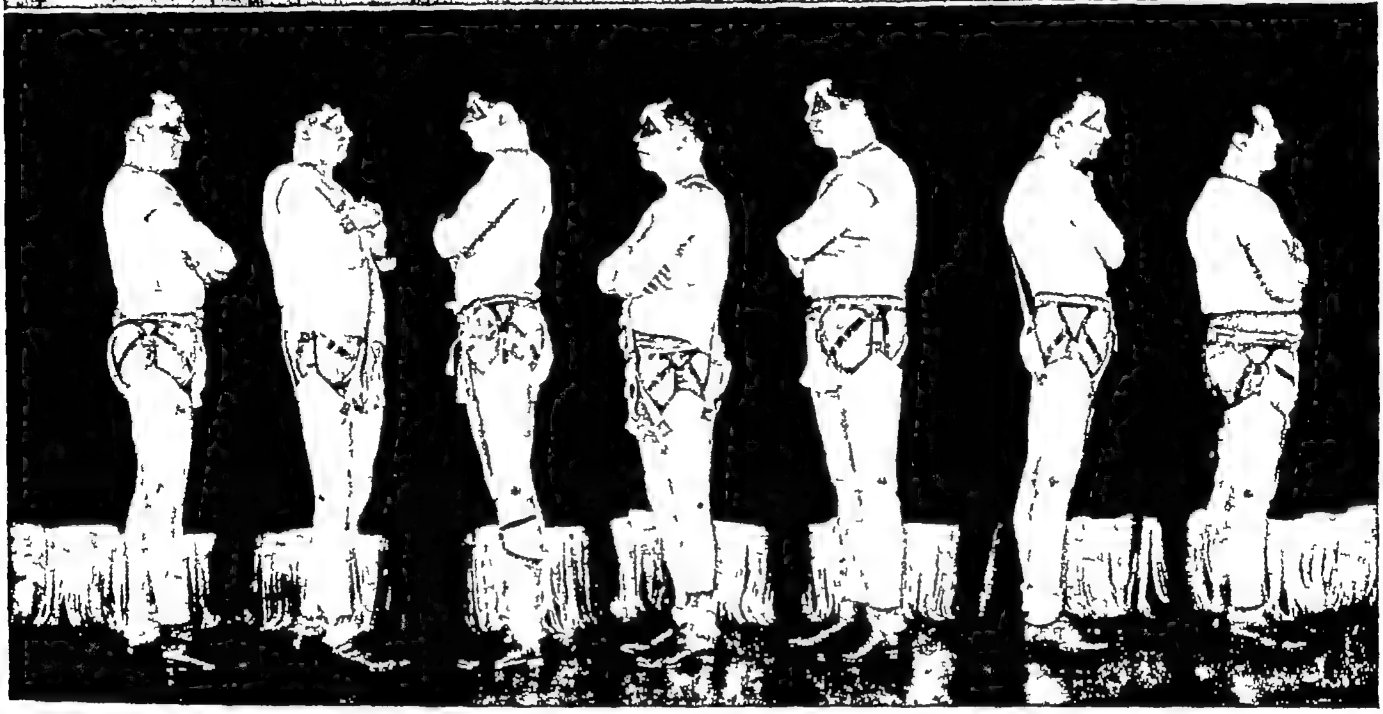

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Figs 434 and 435—Front and side views of hip amputees wearing their prostheses Note the variations in the suspension of the limbs, and in the size and configuration of the sockets (Walter Reed General Hospital Neg No 4649 2, 3)

without additional harness, but the greater number will employ it only for maintaining the limb firmly to the pelvis and will use shoulder strap or straps for suspension

In checking the tilting table limb the examiner first asks the patient to walk, and any rotational defects are noted and corrected Since both knee and hip joints are locked, the limb is fully extended during all phases of the step, and the amputee must as a consequence swing the prosthesis in abduction in order for the foot to clear the ground To facilitate this movement the limb is usually shortened One inch less than normal length is usually sufficient to allow the forward swing without excessive abduction, any greater discrepancy

Fig 436—X ray of the pelvis showing bilateral disarticulation of the hip (Walter Reed General Hospital Neg No 4036 1)

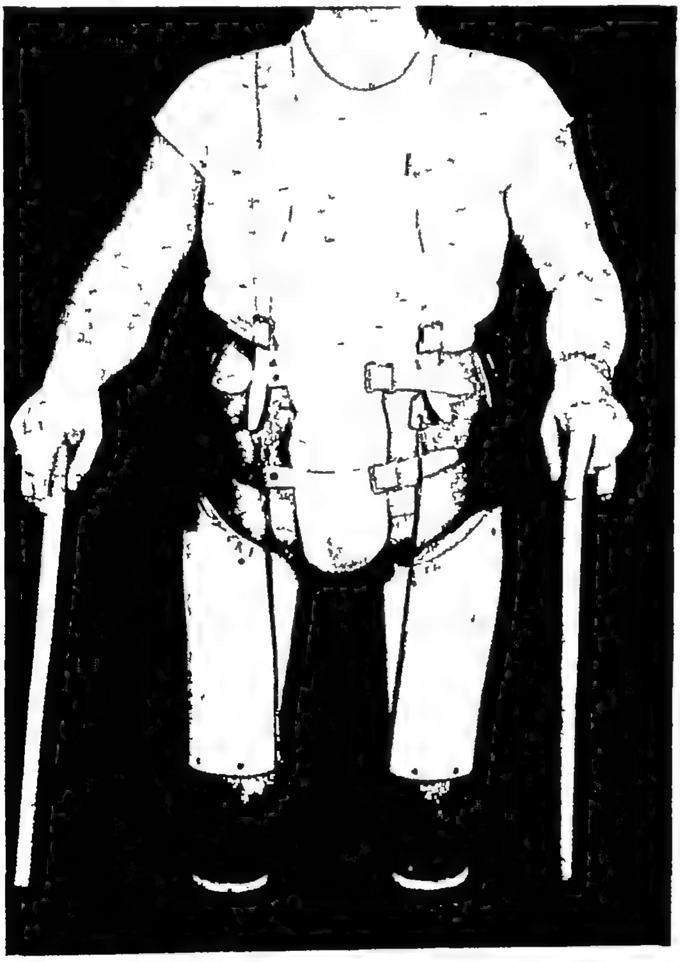

Fig 437—Pylons worn for initial training in the use of the prostheses Lacking height with these the patient was able to learn balance and stability (Walter Reed General Hospital Neg No 4036 3)

has deleterious effects upon the general body mechanics The patient is next asked to stand, and the socket is checked to see that it fits the pelvis snugly, that it extends upward to the level of the iliac crest, that weight is carried on the ischial tuberosity, and that there is no pressure on the perineal structures The pelvic belt is examined to determine that it fits snugly and securely about the opposite side of the pelvis Lastly, the patient is requested to sit The examiner notes any rotation in this position and checks to ascertain that, with the hip joint unlocked, the thigh flexes to 90 degrees

Fig 438—The patient and the prostheses Note that the two sockets are fastened together by horizontal straps The patient, when wearing these prostheses, was five inches shorter than his normal height, the limbs having been made shorter than the lost normal extremities in order that he might have greater control over them With the aid of two canes he was able to walk a city block

The *above-knee limb with a special molded socket* can only be used when the stump extends several inches below the greater trochanter The stump of this length cannot be fitted with the conventional above-knee socket, and yet the tilting table type of hip prosthesis would not take advantage of its uneven contour and its length, which is greater than that of the usual hip amputation In order that these qualities may be utilized toward the stabilization of the limb, a specially constructed socket and thigh piece can be used and the placement of the hip joint modified in an otherwise conventional above-knee limb The socket and thigh piece extend upward to the inguinal ligament on the anterior aspect of the stump and several inches higher than usual on the posterior lateral aspect, the medial border is conventional in type The hip joint is placed anteriorly so that it does not flex as the pelvis moves forward, but rather binds

so that the pelvic motion is directly transmitted to the thigh piece Such placement, however, allows flexion of the thigh when the patient descends to the sitting position The remainder of the prosthesis is the standard above-knee limb with the exception of the knee assembly which usually has no brake and is locked during stance and gait This type of limb is preferable to the tilting table because it requires no manual locking and unlocking of the hip joint, and is lighter in weight, more stable, and less inclined toward rotation

THE SUCTION SOCKET PROSTHESES

The suction socket artificial limb has only recently been introduced into this country from Germany where it has been used successfully for many years for the above-knee amputation and experimentally tried with somewhat less

THE SUCTION SOCKET ABOVE KNEE LIMB

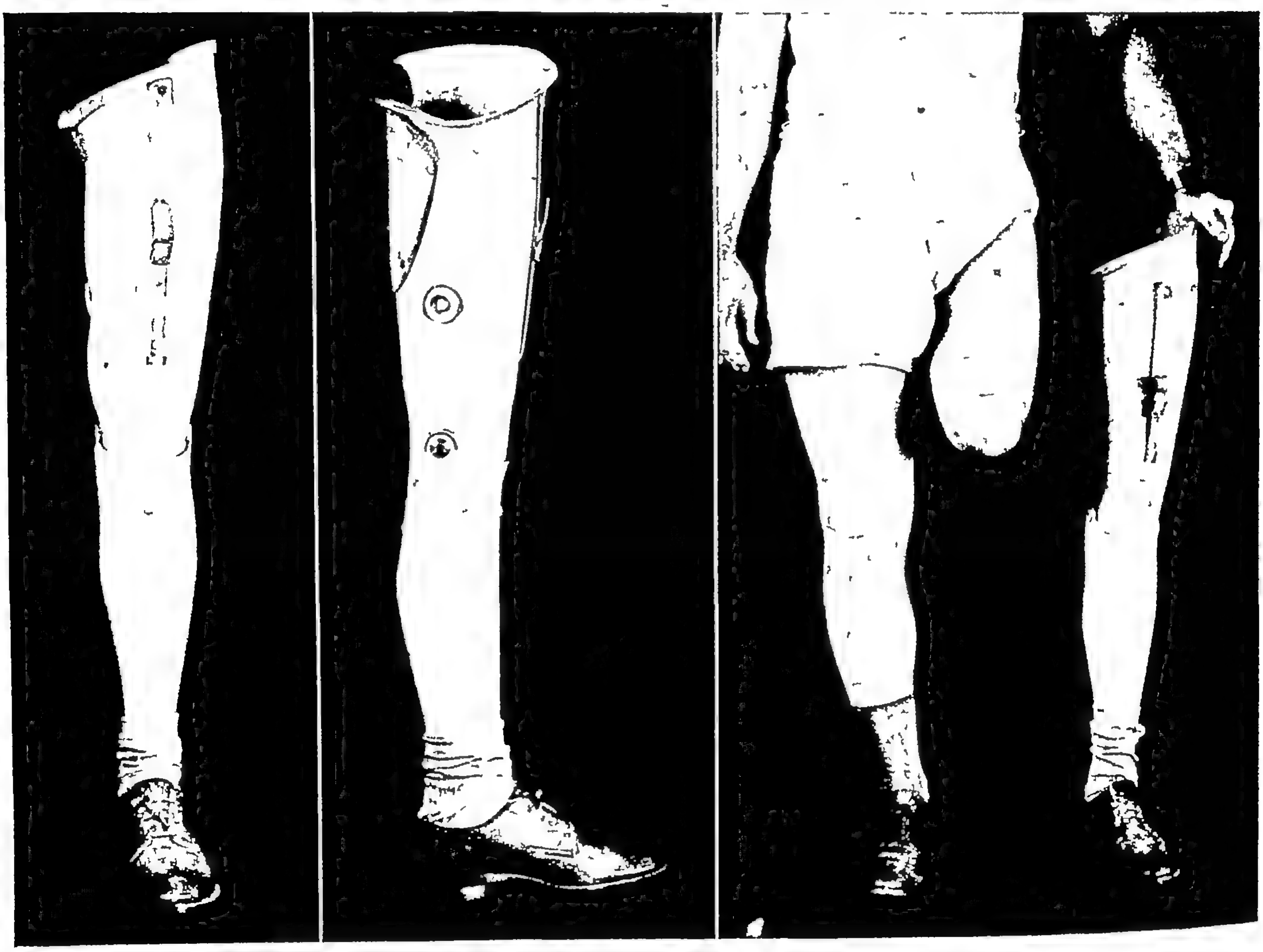

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Fig 439—Front view Note the absence of the pelvic belt and hip joint, note also that the extensor strap is attached to the upper end of the thigh piece (Walter Reed General Hospital Neg No 4961 A2)

Fig 440—Side view Note the valve on the medial aspect of the thigh piece Placement of this valve will vary with the length of the stump and the handedness of the patient (Walter Reed General Hospital Neg No 4961 A1)

Fig 441—The limb and the stump Note the cylindrical shape of the ideal stump for use in the suction socket limb (Walter Reed General Hospital Neg No 4992 A11)

success for other levels of the lower extremity and for some amputations of the upper extremity. The American limb embodies the principle of its predecessor, but has been modified through scientific investigation of stump anatomy and physiology. Its use has been almost entirely limited to the above-knee amputation. The principal feature of the suction socket prostheses is the elimination of all harness—shoulder straps, pelvic belt, and hip joint—for which it substitutes suspension through suction created in a closed chamber containing the amputation stump. The result is increased comfort, direct control of the limb by the amputation stump, and improved function because of the greater freedom of movement.

APPLICATION OF THE SUCTION SOCKET LIMB

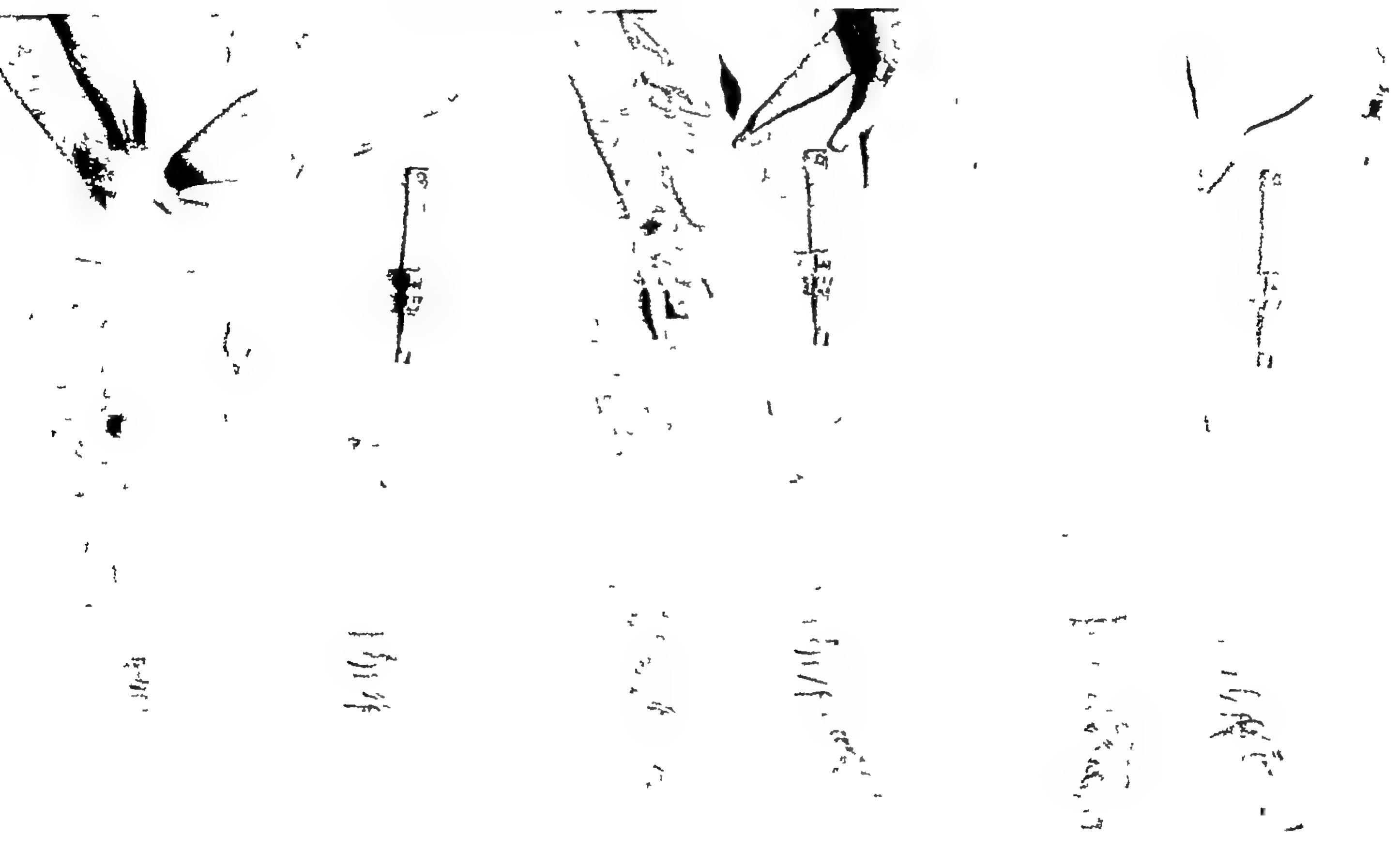

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Fig. 442.—A thin cotton sock is placed on the stump. Note that a string is attached to the bottom of the sock; when the stump is placed in the limb, this is threaded out through the valve to facilitate drawing the sock from the stump. (Walter Reed General Hospital Neg. No. 4992-8.)

Fig. 443.—The stump is placed in the limb and the sock pulled out through the open valve. (Walter Reed General Hospital Neg. No. 4992-9.)

Fig. 444.—Weight is placed firmly on the limb to evacuate any possible air, the suction valve is closed. The limb is now ready for use and is maintained on the stump through negative pressure and muscle action. (Walter Reed General Hospital Neg. No. 4992-A7.)

In prescribing the suction socket limb, care should be taken to discern the mental and emotional capabilities of the patient and the physical characteristics of the stump. The patient should be of a psychologic make-up to cooperate during the preliminary stages of the adjustment of the limb, for with this type of prosthesis the period of fitting and training is considerably more extended than it is with the conventional. The stump should be of ideal length (although occasional successful operation with the above-knee amputation has been reported

with stumps as short as three inches below the perineum), the capillary fragility should be low, since cases with high capillary fragility will definitely be adversely affected by the negative pressure within the socket, no infection, chronic skin disease, or excessive scarring should be present (although moderate scarring and vascular disease are not considered contraindications) Until further observation can be made in this country of the effects of the suction socket limb upon the amputation stump, only those amputees with a healthy opposite (normal) extremity should be fitted, for if ill effects on the stump are forthcoming, the lack of a sound, whole leg would indeed be crippling

Standard parts are used for the limb in all but the socket and the piece which contains it The socket is designed to fit the entire length of the stump snugly, the upper rim is contoured with utmost care, and the portion immediately below the rim is undercut slightly to insure suction The piece in which the socket lies also contains the vacuum chamber, the walls of which are the sides of the shell, the end of the stump, and a transverse wooden block which seals the distal end This chamber usually occupies a space of about two inches beyond the end of the stump, which allows a capacity of about four cubic inches If a larger chamber is created, the vacuum is found to be less efficient In the side wall of the chamber (below the end of the stump) a valve is placed in a position which will be most convenient to the patient This will vary with handedness and the extremity to which the limb is fitted The valve should be of a type which allows automatic expulsion of air from the chamber at positive pressures over one-half pound, and automatic intake at negative pressures over one and one-half pounds It should be equipped with a push button release so that the vacuum can be destroyed when the limb is to be removed or when relief from the negative pressure is desired To apply the limb the patient first dons a thin cotton stump sock with a string attached to its lower end He then places the stump in the limb with the string drawn through the open valve As he forces the stump downward into the socket, he pulls the stump sock out through the valve He then puts weight upon the stump a time or two and screws the suction valve tightly closed If the limb is properly applied, no further adjustment is necessary To remove the limb the wearer simply presses the push button release to destroy the vacuum and the limb slips off

In considering the consequences of adapting this type of limb to the stump, three questions naturally arise What is the effect of suction upon the stump? What changes do the muscles undergo? What is the effect of placing the bare skin in direct contact with the walls of the socket? Since the majority of the factual data available for evaluation and analysis of this type of fitting is gleaned from observation of the above knee amputation, it will be found in the following discussion of these pertinent questions that specific clinical references pertain chiefly to the suction socket as applied to the proximal-bearing thigh stump

What is the effect of suction upon the stump? The question of edema comes foremost to the mind In the first place, the socket must fit the stump very snugly if a vacuum is to be created and maintained this necessitates very accurate fitting about the upper end of the stump if impairment of venous and lymphatic flow and subsequent edema are to be avoided Clinical tests have shown that the critical point in fitting the thigh stump is the strict avoidance of undue pressure in the femoral triangle and that if returning circulation is not retarded at this point, the slight constrictive action of the remainder of the socket has no deleterious effects In the second place, the stump is subjected to negative pressure which, if excessive, is known to create edema The danger point of the exertion of negative pressure is 3 0 pounds per square inch, if control

measures maintain the pressure below this point, edema of a normal stump need not be feared. It is for this reason that valves permitting an air leak when pressure rises above 1.5 pounds per square inch are desirable. In the above-knee limb the piston action of the stump within the socket creates positive pressure during weight-bearing and negative pressure during the swing phase of gait. This alternation of pressure ranges ideally between 0.5 pound per square inch positive to 1.5 pounds per square inch negative. It has been found with this weight-bearing stump that it is a wise precaution for the amputee to release the pressure when sitting for prolonged periods. In addition to edema the question of capillary fragility arises when the effect of suction is under consideration. If the negative pressure is too great, the capillaries will rupture with the appearance of petechiae. If capillary fragility is high, the rupture may even occur at pressures considered to be safe for normal individuals. Tests should therefore be taken to determine this factor before the suction socket limb is constructed. It is interesting to note that edema and petechiae occur only at the end of the stump. This is readily understood when it is appreciated that only this area is subject to negative pressure since it is the only portion of the stump which forms a wall of the vacuum chamber. To date, no abnormal changes have been noted in the stumps of individuals subject to peripheral vascular disease. Indeed, some have hypothecated that the effect will actually be beneficial to such a stump where the alternation of pressure may be compared with the positive-negative pressure apparatus used in the treatment of this condition.

What changes do the muscles undergo? The muscles of the stump respond differently from the way they do in the conventional socket. During the first several weeks of use, the stump shrinks. This response is due to the normal atrophy of muscle under pressure and is frequently enough to cause loss of suction. With continued use of the limb, however, there is a functional hypertrophy and the stump gradually increases in size, becoming finally cylindrical rather than cone shaped. It is therefore readily understandable that there is need for constant readjustment of the limb during the initial period of use. For this reason the limb is usually constructed of seasoned willow wood which, because of its adaptability, can be altered to meet the changes in the stump. Both metal and plastic have been used successfully but alterations are somewhat more difficult.

What is the effect of placing the bare skin in direct contact with the walls of the socket? Clinical evidence testifies that no untoward results have accompanied this type of application where a high grade lacquer, cellulose acetate, or wood paste in a beeswax base have been used upon the inner surface of the socket. Excessive skin irritation has not been noted nor has perspiration been a factor for concern. In a few cases where the inside of the socket has seemed very "slick," the stump has been inclined to slide up and down, causing some irritation. In these instances the situation has been readily corrected by a slight roughening of the inner surface of the socket.

THE WALKING PYLON

Pylons such as these were popular in years past as a provisional apparatus to be used for ambulation while the stump was shrinking In recent years they have been gradually discarded because their use leads to the establishment of poor gait habits which are difficult to correct after the patient obtains his permanent limb The socket of the pylon is constructed of plaster and incorporates the same weight bearing points as those used in the artificial limb

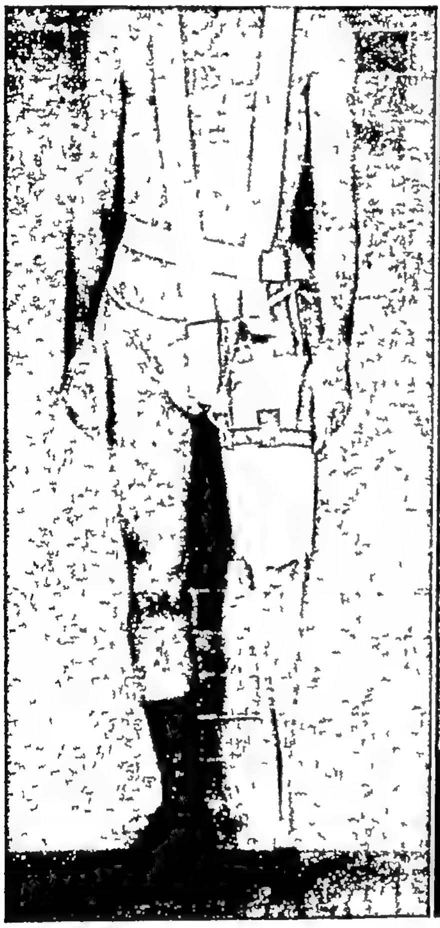

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Fig 445—The above knee pylon constructed of crutch and plaster socket Shoulder harness is used rather than pelvic belt

Fig 446—The below knee pylon utilizes the conventional belt and Y type of extensor strap, and is constructed with a metal frame, articulated at the knee, and plaster socket

LIMB MAKERS' POINTS OF MEASUREMENT FOR THE BELOW-KNEE LIMB

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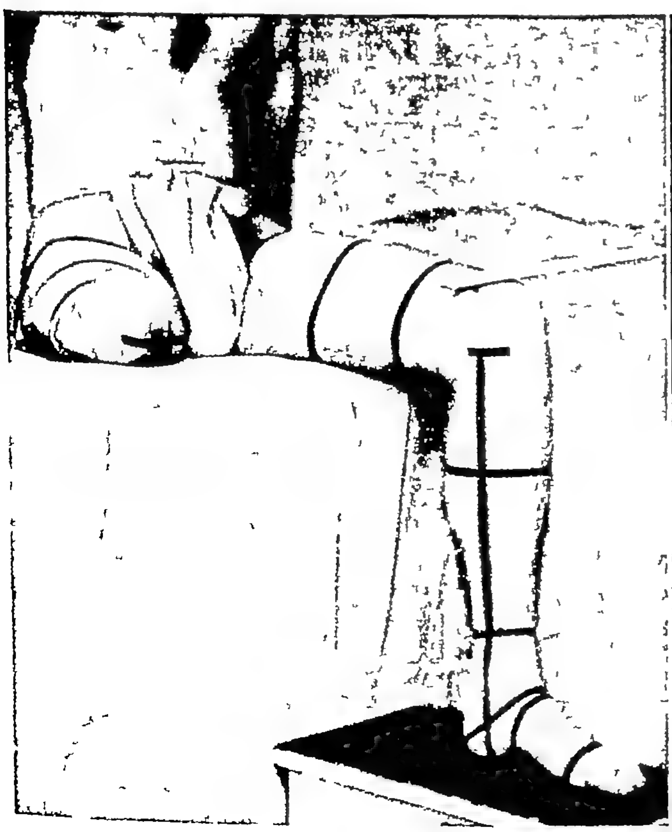
Fig 447.—On the amputated side the two points of measurement of the thigh and a tracing of the stump are shown (The stump tracing usually extends further up the thigh, but those lines are omitted here for the sake of clarity) The U shaped figure on the stump tracing represents the patella, and the two short lines running horizontally at the sides of the tracing represent the center of rotation of the knee On the normal side, points of measurement of the leg and a tracing of the foot are taken The short transverse line at the top of the perpendicular line represents the center of rotation, the length of the perpendicular line up to this point is taken to ensure that the center of rotation of both knees will lie at an equal height Other measurements are taken to be certain that the artificial leg and foot will be equal in size The foot tracing demonstrates the breadth and shape of the foot, which must be duplicated in the artificial foot so that mated shoes can be worn

Fig 448.—A cast of the below-knee stump is made This is later filled with plaster and a positive model is made, the bony prominences are marked on the model, which is then shaped for use in constructing the socket of the limb

LIMB MAKERS' POINTS OF MEASUREMENT FOR THE ABOVE-KNEE LIMB

Measurements are taken at these points to ensure the proper size of the artificial limb at the various levels A plaster model of the stump is not needed in construction of the above knee limb



PRIMITIVE PROSTHESES

These prostheses were constructed by their wearers while interned in prison camps in World War II Each served its wearer well and afforded satisfactory ambulation

451 452 453

Figs 451 and 452—Classical "John Silver" peg leg, constructed in the Philippines A similar type is still used as a work leg by loggers in the Pacific Northwest, since the foot of the conventional limb tends to catch in forest undergrowth In the side view, note that the stump is considerably longer than "a hand's breadth below the knee," which was the level designated in former days for the stump which was to be used in this type of limb (Walter Reed General Hospital Neg No 4288 1, 2)

Fig 453—The knee after three years' use in a peg leg (Walter Reed General Hospital Neg No 4288 4)

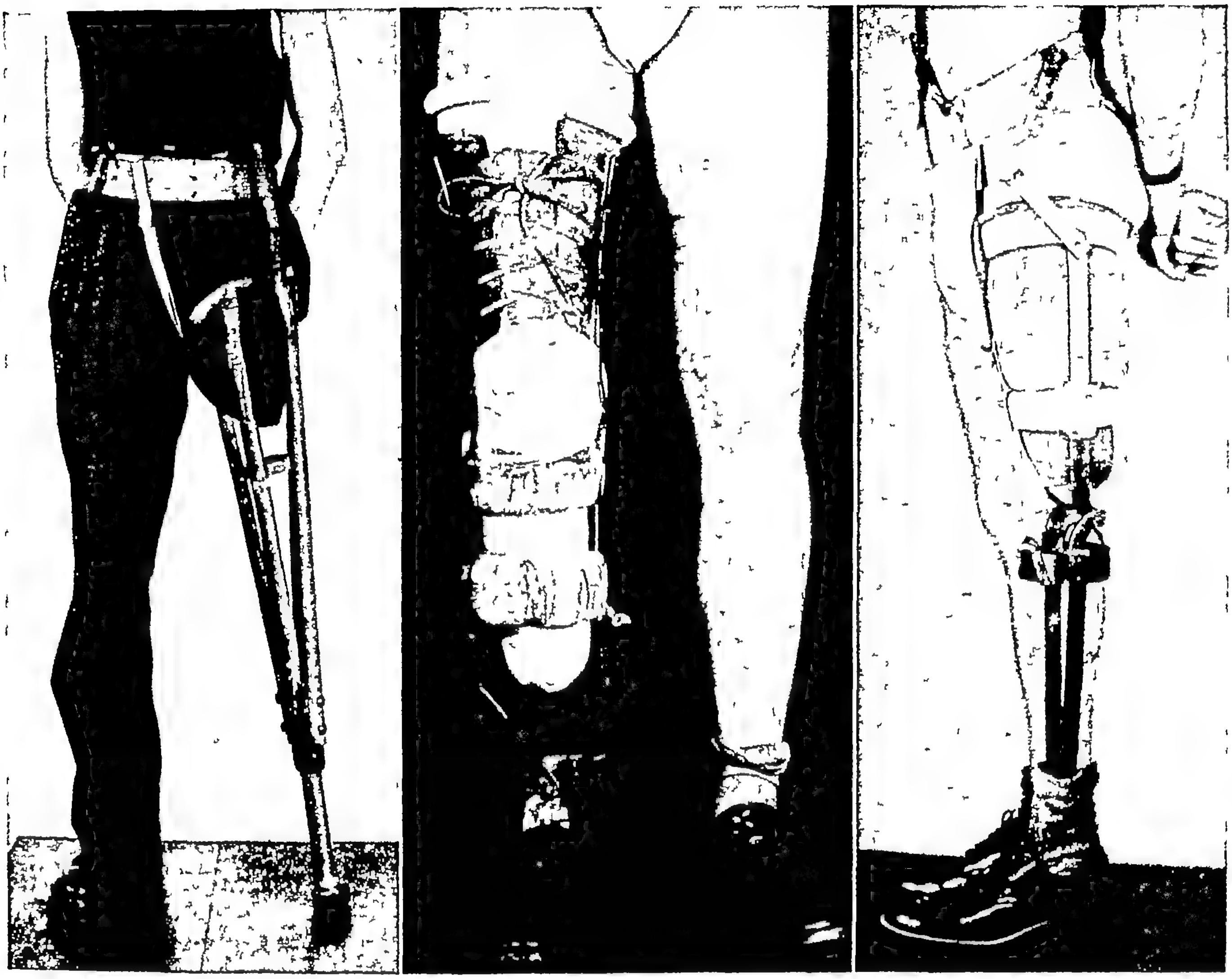


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Fig 454—Above knee peg leg made in a Philippine prison camp from a discarded crutch, bailing wire, rubber hose, and a piece of sink pipe Note that the leg is necessarily in abduction to ensure stability (Walter Reed General Hospital Neg No 4300-4)

Figs 455 and 456—Limbs made of scrap metal in a German prison camp Although crude, they functioned well, for their alignment and articulations were in conformity with the general principles of limb fitting (Walter Reed General Hospital Neg No 4315-2)

XI. PHYSICAL MEDICINE IN THE TREATMENT OF LOWER EXTREMITY AMPUTATIONS

DONALD L ROSE, M D

GENERAL CONSIDERATIONS

Introduction

Physical medicine, as an important adjunct in the management of the lower extremity amputee, owes much of its development in this role to the information gained by the military medical services It is possible that only under the stress of the necessity for therapeutic measures which would hasten the acquisition and mastery of the prosthesis, such as occurs in military service, could such a physical medicine program be evolved, since in this circumstance the necessary combination of personnel and patients would occur With the passage of time and as experience has increased, this program has evolved into a carefully coordinated series of therapeutic events which begins not long after the patient has undergone amputation of the extremity and continues until he has mastered the use of the prosthesis

The physical medicine program has been devised in some detail, not for the purpose of making this procedure seem unnecessarily complicated, but with the dual hope that the steps outlined may serve as a general guide for those interested in this field and that, as additional clinical experience is gained, further development of this program will occur as a matter of course

Correlation With Related Fields

Important though physical medicine may be, other fields likewise contribute materially to the treatment program Definite provisions should be made for the inclusion of all agencies which can serve a useful purpose Even activities which are strictly diversional can fill gaps in the program which otherwise constitute a problem both to the patient and to his physician It is only fair to assume that these diversional activities will be confined to such gaps in the program and will not encroach on the more actively therapeutic procedures There should be close coordination between the orthopedic surgeon and the various groups interested in the patient, and equally close cooperation among these groups No one group must feel that its is the most important, if it does, sooner or later there will be overlapping of treatment efforts, injured personal and professional feelings, and gaps in the treatment program All of these factors are deleterious and react ultimately to the harm of the patient who, after all, is the reason for the existence of the program It is strongly urged that the responsible individuals of each of the fields concerned submit to the physician in charge of the program a written outline of what can be accomplished for the patient by them and that he set up the general program incorporating such features as are desirable in the light of the welfare of the patient

Orientation of the Patient:

One of the most unfeeling things that can be done to the patient is to hand him his prosthesis without adequate psychological preparation for it. Detailed discussion of such preparatory measures is not within the province of this chapter. However, it is as important for the physiatrist and the physical therapist to realize these factors as for any other group which may actually execute them.

The patient regards the acquisition of the limb as the achievement of a goal, the culmination of weeks or months of waiting, one or more surgical procedures, and certainly a measure of physical suffering. To lead him to believe that he will be able to walk without further ado once the prosthesis is fitted, or that the artificial limb is a complete substitute for the one he lost, is grossly unfair to him. This will lead only to another major disappointment. Regardless of what group is actually charged with the responsibility of carrying out this procedure, there should be open discussions with the patient at the proper psychological times, in which he should be advised of the conditions he may expect once he acquires the prosthesis. He should understand the mechanics of the prosthesis, its limitations, and how it functions in use. He should know that no prosthesis fits comfortably immediately, that it will be awkward to use in the beginning, that he cannot walk on it indefinitely to begin with, and that a definite training period in the use of the limb is just as necessary as the most important of the other procedures that are employed. These discussions can be casual and properly timed so that their repetition will not give the impression of defeatism or "the build-up for the let-down." Let the acquisition of the prosthesis represent the achievement of a goal, but let it be an occurrence the major imports of which are already known.

General Purpose of Physical Medicine

The nonsurgical aspects of the management of amputations in the past has frequently been a discouraging problem. Frequently it was necessary to delay the fitting of the prosthetic limb. During this nonambulatory period, abnormalities in body mechanics developed insidiously. Prominent among these abnormalities were weakness of the anterior abdominal musculature and contracture of the hip flexor muscles of the involved extremity; these defects made subsequent fitting of and walking with the prosthesis a difficult procedure. Minor disappointments in the function of the prosthesis were frequently magnified to the point of discarding it, the amputee resigning himself to a wheel-chair existence or to ambulation with crutches. In the event of this negative ending, perhaps the best that can be concluded, from the standpoint of having truly aided the patient, is that he successfully survived the surgical procedures.

In contrast to this picture is the genuinely inspiring one of the amputee who walks the crowded streets with a gait so little different from the average individual as to be inconspicuous, who steps easily from and into his automobile or from the curb to the street and back again, and who in general performs the functions of normal ambulation without difficulty or conspicuous effort. Such an individual has indeed been benefited if medical care has contributed to such a happy end result.

The purpose of presenting these contrasting pictures is not to imply that physical medicine is responsible for the difference between them. However, to the extent that physical medicine has improved a functionally inadequate circulation to the extremity, has aided healing, has maintained or restored the normal body mechanics and muscular balance, and has trained the individual in the use of his prosthesis, then to this field should not only devolve recognition for its

share in the treatment of such an individual, but also such recognition should stimulate interest in the further development of physical measures

The means for achieving the therapeutic ends for which physical measures are prescribed vary with the clinical picture For this reason it is to be emphasized that there is no physical medicine "routine" in the management of the lower extremity amputation Any attempt to reduce treatment to a stereotyped form will never produce the successful results seen when the general program is intelligently modified to meet the needs of the individual patient

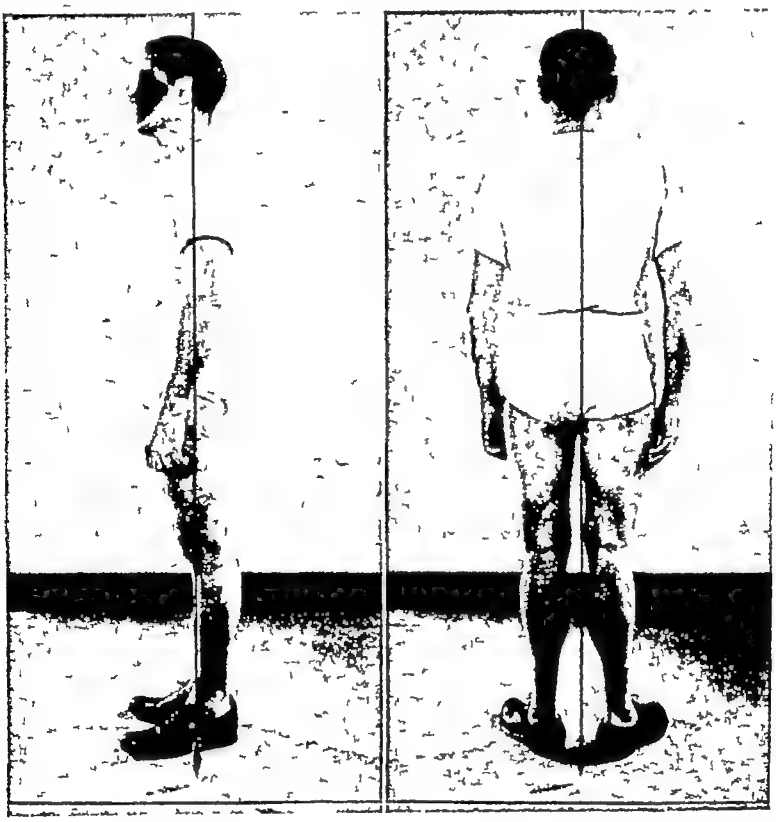
With the specific understanding that the program presented in this chapter can and must be modified in the light of individual necessity, the following may be considered to represent the present-day management of the average lower extremity amputation by means of physical medicine

EVALUATION OF BODY MECHANICS

Postural Examination

Normal Posture.

It is commonly recognized that in the otherwise normal individual deviations from certain postural standards are so consistently associated with physical complaints as to constitute a degree of disability The same problem



A *B*

Fig 457—*A*, Normal posture in the nonamputee Anteroposterior plumb line test

The plumb line passes through a point just anterior to the lateral malleolus, the knee joint posterior to the patella, the hip joint, the mid abdominal region laterally, the shoulder joint, and the lobe of the ear

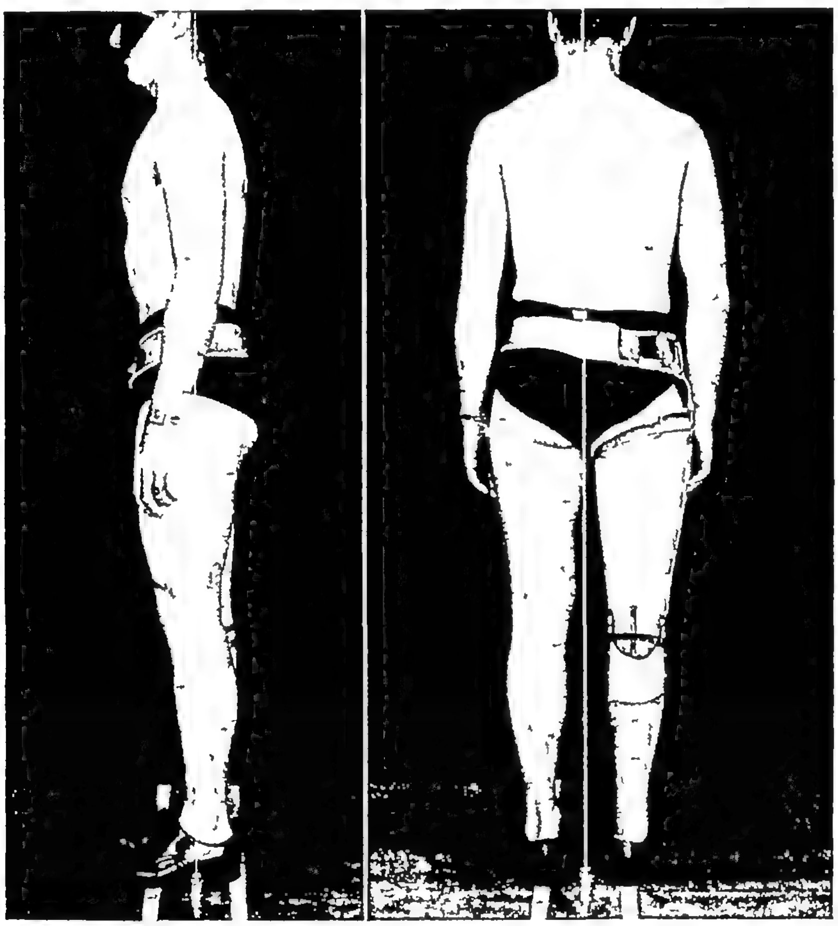
Minor deviations in the subject are hyperextension of the knees, pelvis forward, shoulder backward, and head forward These deviations are within acceptable normal limits

B, Normal posture in the nonamputee Lateral plumb line test

The plumb line passes through a point midway between the medial malleoli, the coccyx, the sacrum, and the spinous processes of the remainder of the vertebral column

exists in the amputee with the exception that it is further complicated by the engrafting of one disability onto another As a general statement, experience has shown that the amputee who is an excellent walker has few if any abnormalities in body mechanics, whereas a similar amputee who manages his prosthesis poorly has easily demonstrable faults in posture and muscle balance, with improvement in the faults in body mechanics, the prosthesis is utilized more efficiently The search for and correction of abnormalities in body mechanics is one of the major contributions of physical medicine to the management of the amputation problem

In the normal individual proper posture is such that the various body segments are held in good alignment by the balanced state of the body musculature The alignment of the body segments may be quickly and accurately determined by means of plumb-line measurements



A *B*

Fig 458—*A*, Normal posture in the amputee Anteroposterior plumb line test

The plumb line passes through a point just anterior to the lateral malleolus, the knee joint just posterior to the patella, the hip joint, the mid-lateral abdomen, the shoulder joint, and the lobe of the ear

Minor deviations, within normal limits, in the subject are slightly forward head and shoulders (Walter Reed General Hospital Neg No 4525 A9)

B, Normal posture in the amputee Lateral plumb line test

The plumb line passes through a point midway between the medial malleoli, the coccyx, the sacrum, and the spinous processes of the remainder of the vertebral column (Walter Reed General Hospital Neg No 4525 A16)

Anteroposterior Alignment

When a plumb line is hung lateral to the body with the plumb bob just anterior to the lateral malleolus, it will be found that the anteroposterior align-

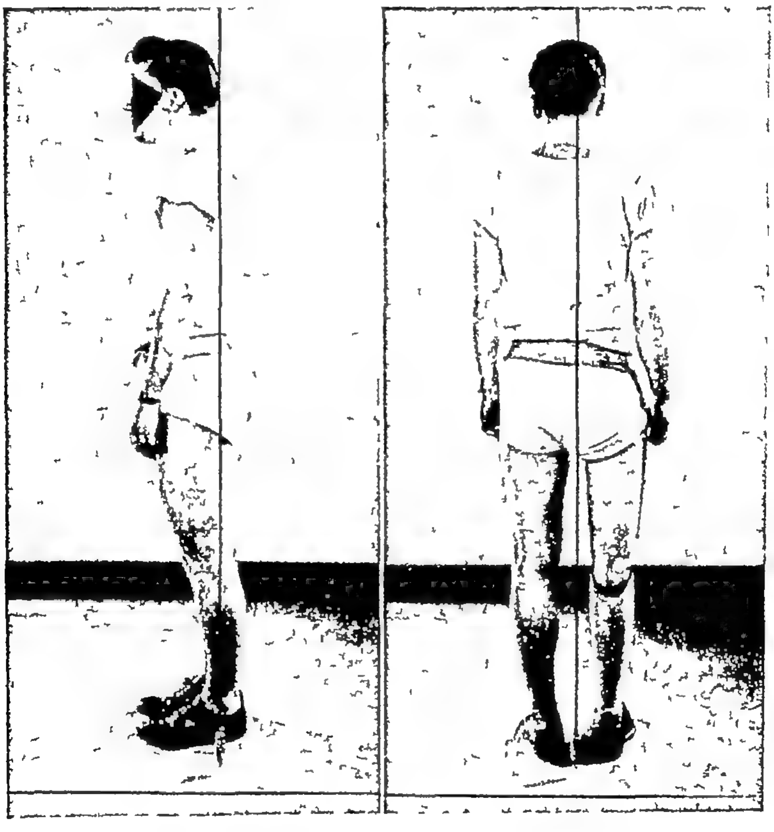
ment of the body segments is such that the plumb line passes through the knee joint posterior to the patella, through the hip joint, through the shoulder joint, and through the lobe of the ear

Lateral Alignment

When the plumb line is hung with the plumb bob midway between the medial malleoli it will be found that the lateral halves of the body are symmetrically distributed on either side of the line

In the nonamputee

Fig 457 illustrates a nonamputee who exhibits a posture which may be classified as within normal limits, although it does not conform exactly to the definition of "normal" posture In this illustration, the subject was deliberately not instructed in how he should stand but was told only to stand as he would ordinarily, by this means it was felt that a truer representation of normal posture in the average individual would be obtained



A B

Fig 459—A, Abnormal posture in the amputee Anteroposterior plumb line test. Postural errors noted in the subject include forward knees, forward hips, marked lordosis with clockwise rotation of the pelvis, forward shoulders, and head These errors were initiated by contracture of the hip flexors of the stump side Compare also with Fig 474

B, Abnormal posture in the amputee Lateral plumb line test

Postural errors noted in the subject chiefly concern unequal weight distribution on both feet so that a disproportionate share of the body weight is borne on the normal leg

In the amputee

Fig 458 illustrates the anteroposterior and lateral postural alignment in a unilateral, mid-thigh amputee With the exception of a position of slightly forward head and shoulders his posture is excellent This subject had received

considerable postural training and was definitely "posture conscious," as may be detected from the contracted anterior abdominal musculature and the elevated thoracic cage Such posture consciousness is to be encouraged, for it provides the incentive for the maintenance of proper posture—a status fundamental to the achievement of the skillful use of the prosthesis

Abnormal Posture in the Amputee

The value of the plumb-line measurements as adjunctive aids in the diagnosis of abnormalities in body mechanics, either as a result of muscular imbalance or a malfitted prosthesis, is apparent from the following illustrations

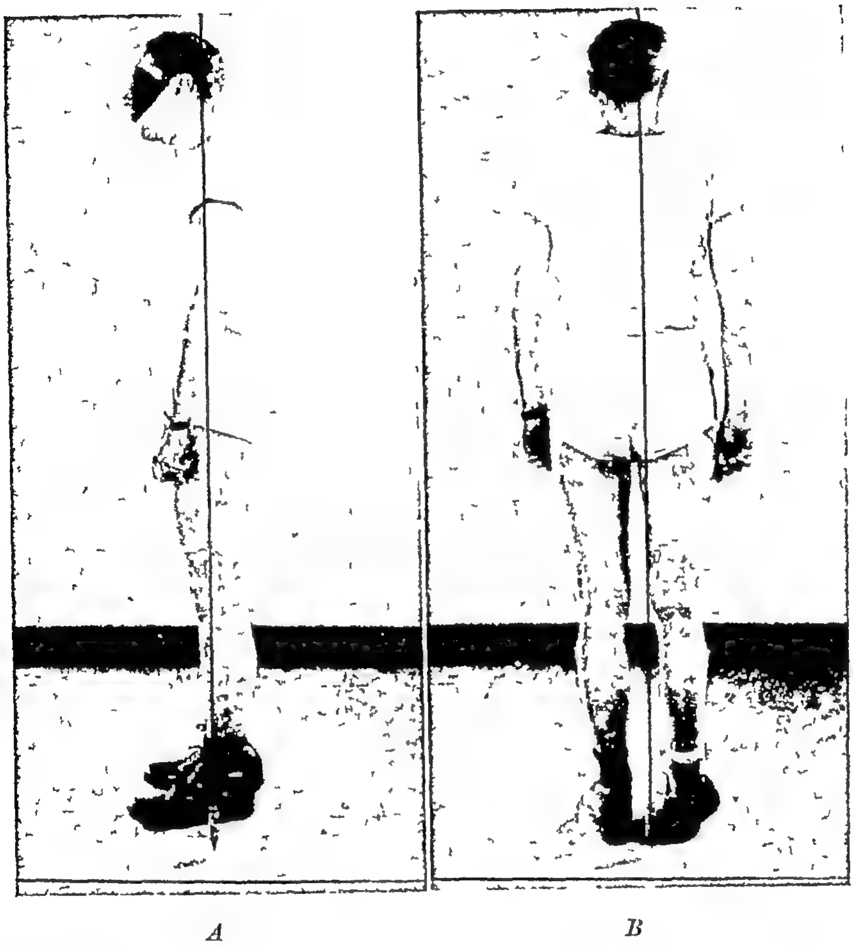


Fig 460—Plumb line tests Chopart type amputation, right foot

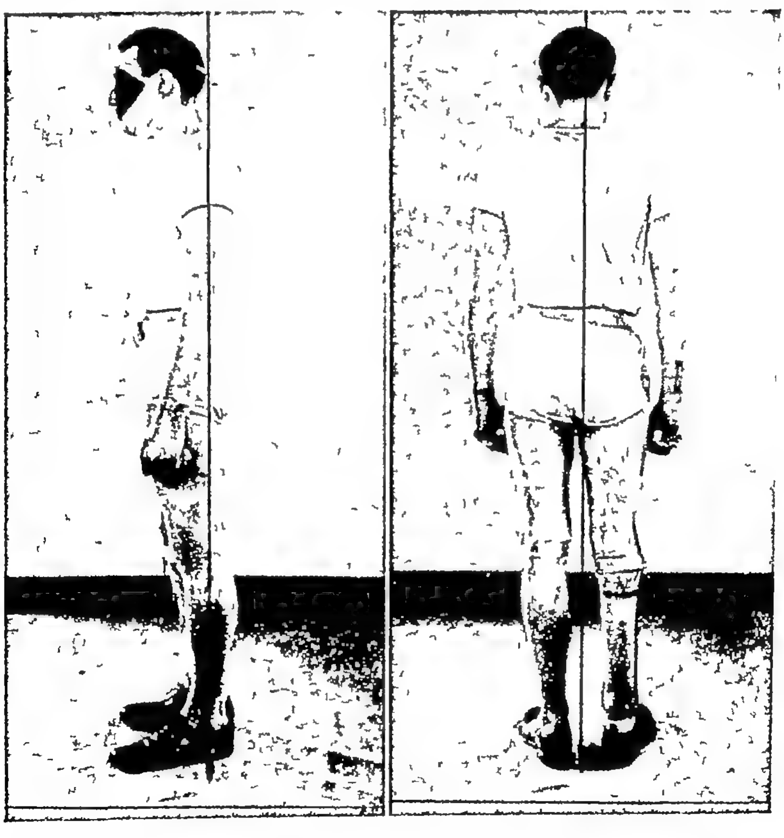
A, Anteroposterior position demonstrates normal segmental alignment except for slightly forward head Muscle balance excellent

B, Lateral plumb line test shows uniform displacement of the body to the left The patient was unable to bear the body weight equally on both feet because of pain in the right foot

Fig 459 demonstrates the marked deviation from normal posture in the case of an individual with a mid-thigh amputation This patient was fitted with his prosthesis without an effort having been made to ascertain whether defects in body mechanics existed or to institute measures designed to correct them A hip flexion contracture of 35 degrees resulted in the severe degree of lordosis noted in Fig 459, *A*, the weakness of the anterior abdominal musculature and the general anterior displacement of the body which places a constant strain on the normal posture-maintaining structures As one might anticipate this patient walked very poorly despite his conscientious attempt to carry out the proper fundamentals of good walking This case also illustrates the fine balance which must be achieved in the various factors which enter into proper utilization of

the prosthesis The prosthesis was fitted to the extremity which could be extended only to within 35 degrees of full extension because of the tightness of the hip flexors of that side This position of flexion tended to remain fixed because of the prosthesis Fig 474 illustrates the appearance with the prosthesis in place Assiduous attempts to correct the marked abdominal weakness and to improve the postural defects were fruitless since the lordotic position of the pelvis was automatically assumed whenever ambulation with the prosthesis was attempted When the hip flexion contracture was stretched out by the method illustrated in Fig 495, there was marked gain in the strength of the hip extensors and the anterior abdominal muscles Despite the correction of these defects in body mechanics skill in walking still was not attained until the lateral bar connecting the pelvic band and the thigh piece of the prosthesis was changed so that the position of thigh extension could be assumed With adjustment of the lateral bar, the patient could walk with greater ease and he soon became proficient in the use of the prosthesis The obvious lesson to be derived from this case is the close cooperation which must exist among the various groups concerned with the amputee if he is to achieve the maximum therapeutic benefit from medical care

Fig 460 illustrates the anteroposterior and lateral segmental alignment in an individual with a unilateral, Chopart-type amputation He presents an ac



A B

Fig 461 —Plumb line tests Syme type amputation, right foot

A, Anteroposterior test illustrates marked forward displacement of the pelvis and head Muscle tests demonstrated weaknesses in the lower anterior abdominals, the middle and lower trapezius, the dorsal erector spinae, and the flexors of the cervical spine

B, Lateral plumb line test demonstrates a slight displacement of the body to the left Note also the upward tilt of the pelvis on the left Muscle tests demonstrated marked weakness of the gluteus medius on the left, which, together with the other muscle defects noted, contributed to a moderate limp on walking and fatigue on standing or walking short distances

ceptable normal segmental alignment in the anteroposterior position, but a uniform displacement to the left in the lateral plumb-line test It is obvious from Fig 460, *B* that he bears the majority of the weight of the body on the left lower extremity Pain in the right foot and difficulty in ambulation ultimately led to reamputation of the extremity at the level of the malleoli as shown in Fig 461

Fig 461 illustrates postural deviations in a patient with a Syme-type amputation Such an amputation should under ordinary circumstances lead to little disability It permits full weight-bearing, the prosthesis itself can substitute satisfactorily for the functions of the amputated foot, and in general there should be no disturbance of the body mechanics or of gait This individual fatigued easily on standing or walking for moderate distances The plumb-line tests suggest weakness of the cervical flexors, dorsal erector spinae, and anterior abdominal muscles on anteroposterior examination The lateral plumb-line test suggests weakness of the left gluteus medius which permitted upward tilt of the pelvis on that side and displacement of the body weight to the left These views suggest the muscle weaknesses present, only muscle tests will confirm the presence or absence of specific muscle weaknesses

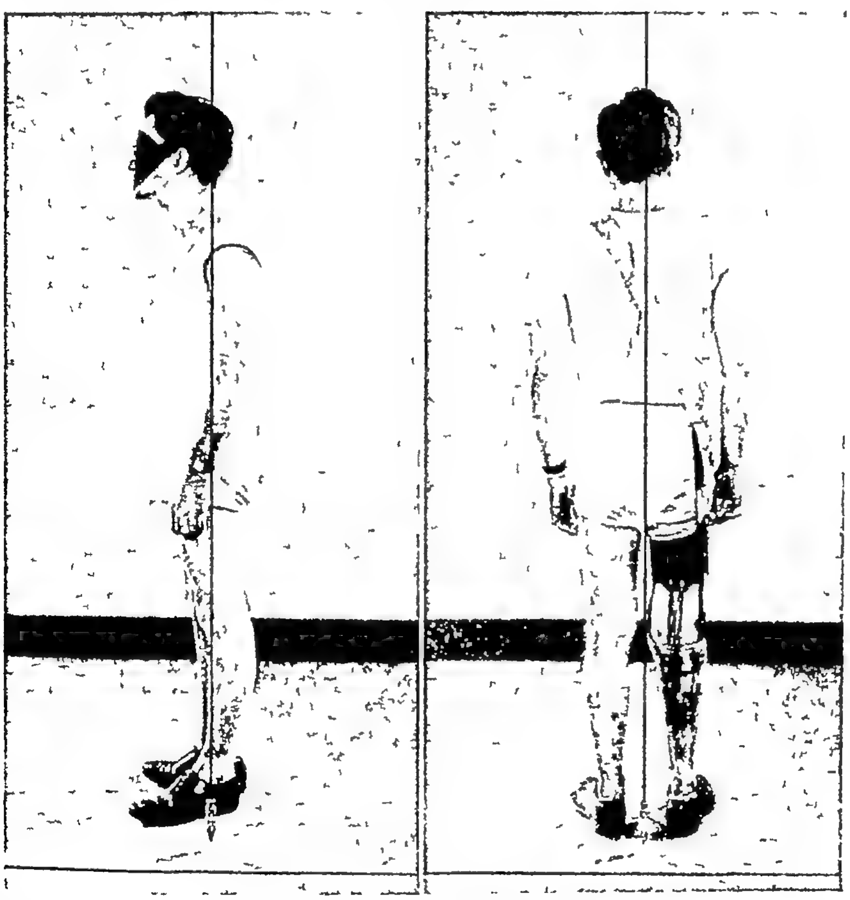


Fig 462—Plumb line tests Below-knee amputation, right

Postural defects similar to Fig 461 are illustrated here In addition to the muscle weaknesses noted in Fig 461, the anteroposterior plumb line test suggest hamstring and gastrocnemius weakness of the left leg as responsible for the genu recurvatum noted The left gluteus medius weakness was less pronounced than that of the patient in Fig 461, and it may be noted that there is less displacement of the body to the left

Fig 462 illustrates postural defects similar to those of Fig 461 in an individual with a below-knee amputation The left gluteus medius weakness was of less degree than in the patient of Fig 461 and there is noted to be correspondingly less shift of the body weight to the left

Fig 463 demonstrates almost as severe a degree of disturbance of body mechanics as that shown in Fig 459 This patient possessed an end-bearing Gritti-Stokes type of amputation In contrast to the patient of Fig 459, there was no significant degree of hip flexion contracture here and the poor postural control illustrated was the resultant of muscle weaknesses, principally of the cervical flexors, the anterior abdominals, the hip extensors of the left thigh and the right gluteus medius It is worth while noting that obesity was also a contributing factor in this instance and dietary restriction was necessary to aid the program of therapeutic exercises

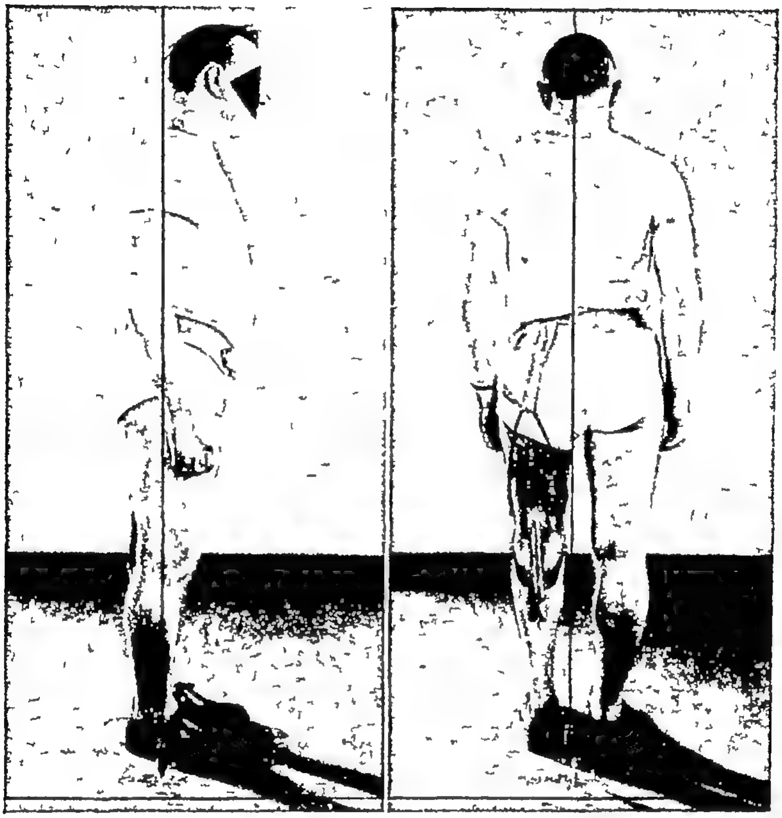


Fig 463 —Plumb line tests End bearing, Gritti Stokes amputation, left

The anteroposterior test illustrates marked lordosis and a markedly forward position of the head The lateral plumb line test illustrates lateral displacement of the body toward the normal, right, side and upward tilt of the pelvis on the right

Muscle tests revealed marked weakness of the anterior abdominal musculature, the hip extensors and the cervical spine flexors

Fig 464 illustrates the same general pattern of postural defects as noted in the preceding figure in a patient with a mid-thigh amputation

Fig 465 is that of an individual with a short thigh amputation The antero posterior plumb-line test would indicate considerable disturbance of body mechanics from the anterior displacement of the body This amount of displacement was permitted for the reason that it permitted locking of the knee of the prosthesis in extension in the standing position The great fear of the above knee amputee is that the knee of the prosthesis will buckle under him unexpectedly, and many of the undesirable traits of poor walking may be charged to this unconscious fear The person with the very short thigh stump, by reason of having less secure control of the prosthesis, has even greater reason to guard

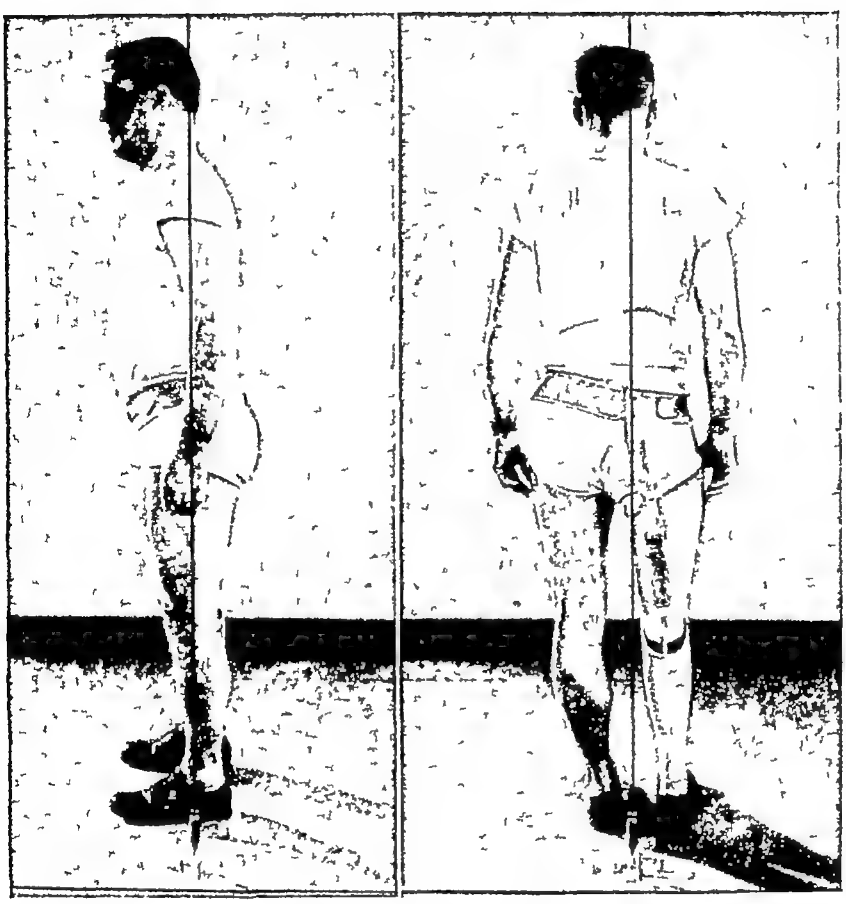


Fig 464 —Plumb line tests Mid-thigh amputation, right

The anteroposterior test illustrates the postural defects of marked lordosis and forward head The lateral test shows displacement of the body toward the normal, left, side and upward tilt of the pelvis on the left The same type of muscle weaknesses, noted in Fig 463, were found in this subject

against the feeling of insecurity of balance If he will have confidence that the prosthesis will *not* buckle at the knee *so long as he bears weight on it when the greater trochanter of the hip is anterior to the knee joint,* one of the major psychological handicaps in walking will have been overcome For this reason, the posture illustrated is encouraged for this type of amputation It should also be noted in Fig 465 that, despite the anterior displacement of the body, the head is held well in extension, the thorax is elevated, the tone of the anterior abdominal muscles appears good and the lateral plumb-line test shows acceptable symmetry of the lateral halves of the trunk on either side of the plumb line Despite the shortness of the stump, the patient was an excellent walker

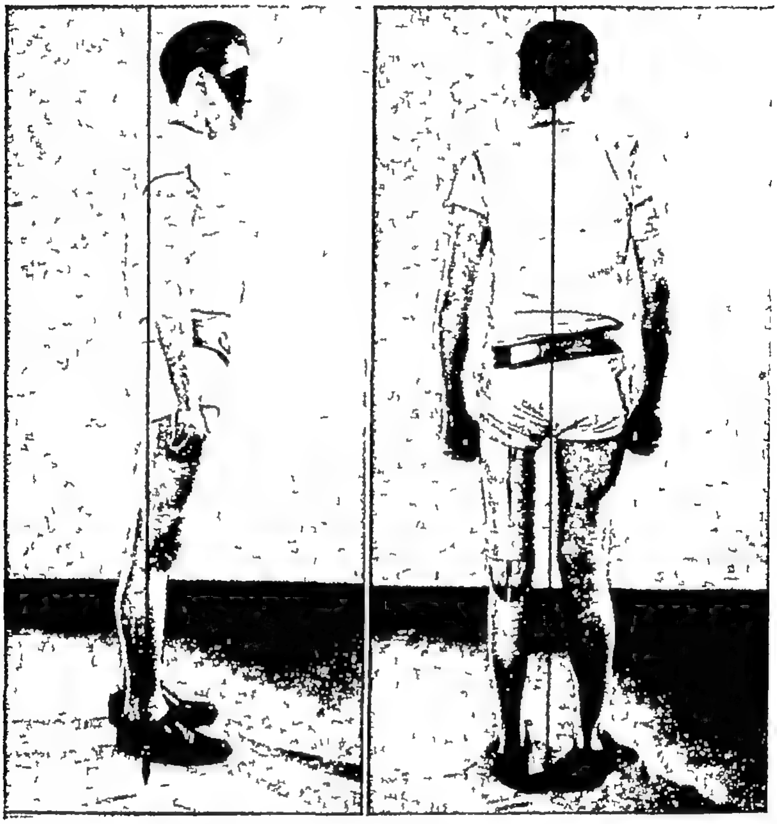


Fig 465—Plumb line tests Short thigh amputation, left

The anteroposterior test illustrates anterior displacement of the body from the knees up Because of the shortness of the stump, this postural deviation is permissible since it enables the amputee to lock the prosthesis knee in extension The lateral plumb line test shows no significant deviation from the normal The pelvis is level, weakness of the gluteus medius on the right could not be demonstrated

Fig 466 illustrates the postural deviations in an individual with a very short thigh stump which also presented a marked abduction contracture Since the contracture could not be corrected, the prosthesis necessarily had to be fitted to the deformity The errors in posture illustrated remained fixed by reason of the contracture and the best that could be expected under this circumstance was to prevent their further development

Fig 467 illustrates the posture in an individual with a hip disarticulation fitted with a tilting-table type of prosthesis The postural deviations seen do not exceed the limitations imposed by the disability, indeed they are less than those exhibited by many nonamputees

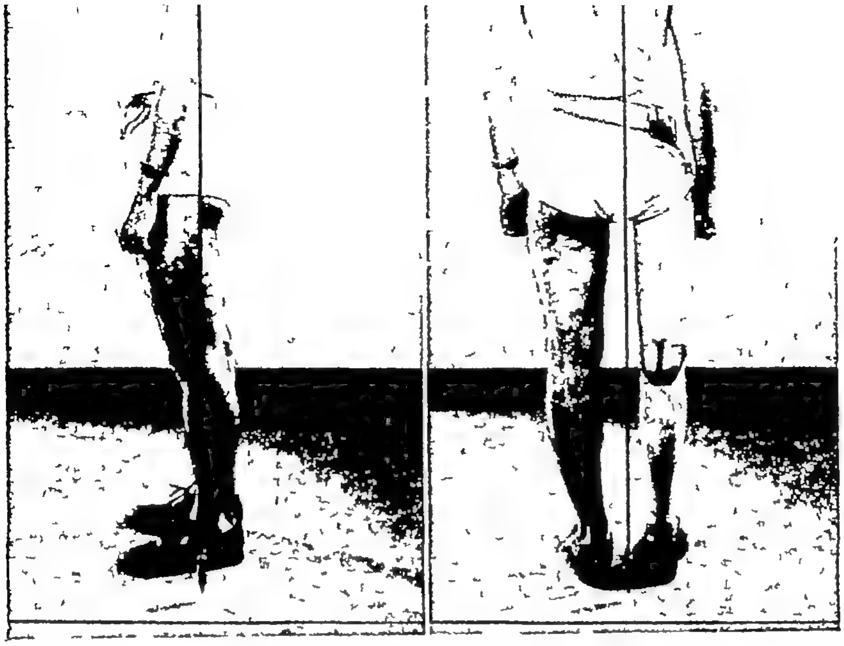


Fig 466—Plumb line tests Short thigh stump, right, with fixed abduction contracture

The anteroposterior test illustrates moderate lordosis and forward head The lateral test illustrates a rather marked lateral deviation toward the left The lateral deviation was predicated by reason of the abduction contracture of the stump The weakness of the anterior abdominal musculature, demonstrated by muscle tests, remained fixed, since the position of forward tilt of the pelvis in standing or walking constantly placed the anterior abdominal musculature at a mechanical disadvantage and prevented successful strengthening of these muscles

Fig 467—Plumb line tests Hip disarticulation, right

The anteroposterior test illustrates moderate anterior displacement of the pelvis and a slightly forward head Aside from a minor lateral deviation toward the normal side, the lateral plumb line test demonstrates no significant abnormality The anterior pelvic displacement is permissible for this type of amputation by reason of the additional security it provides in maintaining extension of the prosthesis knee in weight bearing

The purpose of the preceding illustrations has been as much to demonstrate that *normal* posture is entirely possible of achievement in the amputee regardless of the level of the amputation as to stress the value of the plumb line tests in permitting accurate, rapid estimations of postural deviations

Tests for Flexibility, Extensibility, and Contractures

It is difficult to compare certain procedures in physical medicine so far as relative importance is concerned Certain simple tests for muscle and fascial tightness should be done for the additional information they supply concerning the need for modification of the prescribed exercise program These tests are neither more nor less valuable than muscle tests, but for the information they supply, they are just as important as the muscle tests and should not be omitted

Examination for General Flexibility

a *Purpose* Limitation of either flexibility or extensibility through muscle or fascial tightness will not directly produce postural deformities but will tend to fix any deviation that may be present Strength of certain weakened muscles will not be regained until the limiting factor has been removed (e g, the hip extensors can be strengthened with facility *after* contracture or tightness of the hip flexors has been corrected, they cannot be strengthened *in the presence of* any significant degree of hip flexion contracture) The importance of correctly seeking out and eliminating these limiting factors ranks in importance with the muscle examination

b *Position* Sitting, leg fully extended

c *Test* The patient reaches forward easily with both hands to touch the toes, rounding the lumbar region as much as possible Normally, as shown in Fig 468, the individual should touch the toes without difficulty

d *Note*

1 Insure that the patient does not extend the toes, flex the knees, or lunge forcibly forward in performing this test

2 Note the contour of the back, whether one region remains fixed or assumes most of the forward movement Observe also the amount of motion that occurs at the hip joint (as in occasional cases of hypermobility of forward flexibility due to relaxation of the hamstrings)

3 Aged individuals, arthritics, and those patients with other pathological conditions involving the back would not be expected to accomplish this test with the facility of the young subject illustrated In such instances, restriction of motion is not on a basis of simple muscle or facial tightness and should not be managed therapeutically as are simple fascial contractures

4 Restriction is measured in terms of the number of inches separating the outstretched fingers from the toes

e In the event limitation is found, decision must be made as to its origin Limitation may be due to

1 *Hamstring tightness* Straight leg raising, with the opposite thigh extended, should be possible to 80 degrees in the absence of hamstring tightness As shown in Fig 469, beyond 45 degrees of thigh flexion, flexion of the leg on the thigh began to occur as a result of hamstring tightness

2 *Low back tightness* This ranks second to hamstring tightness in causing limitation of forward flexibility Low back tightness usually can be detected by the fixed position of the lumbar spine during flexion, the entire lumbar region moving as a unit, pivoting forward with the pelvis, with back flexion occurring chiefly in the dorsal region

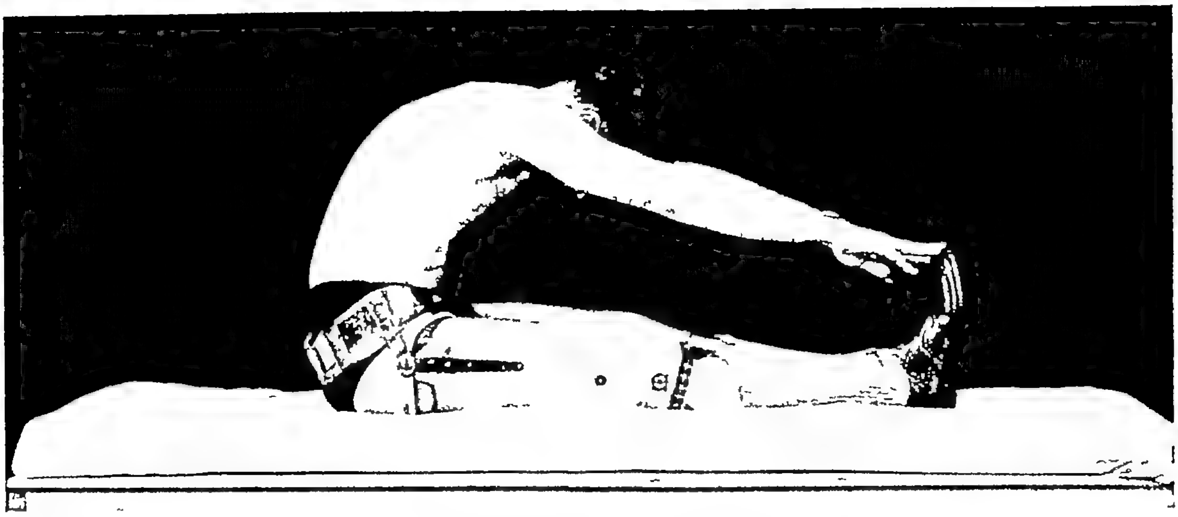


Fig 468—Normal test for general flexibility With the legs completely extended, the subject pulls up and in with the abdominal muscles rounding the lumbar region of the back as much as possible, and reaches forward to touch the toes (Walter Reed General Hospital Neg No 4525 A20)

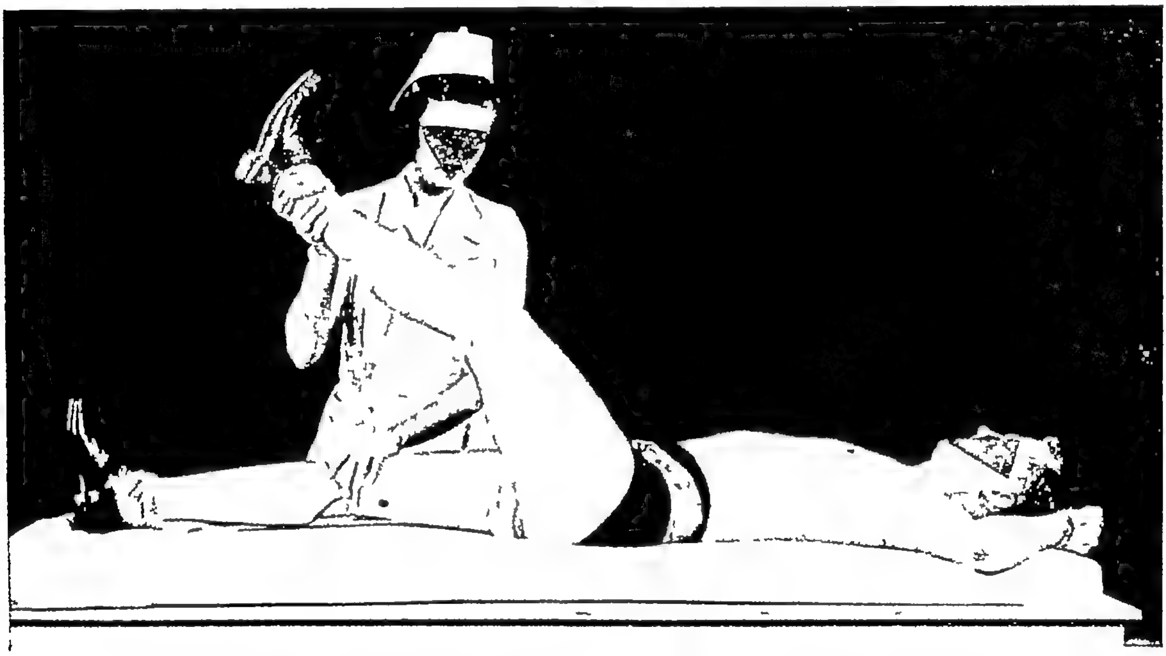


Fig 469—Limitation of flexibility due to hamstring tightness Normally, straight leg raising should be accomplished to approximately 80 degrees without flexion of the leg In this subject, tightness of the hamstrings prevented maintenance of complete leg extension beyond 45 degrees (Walter Reed General Hospital Neg No 4525 A19)

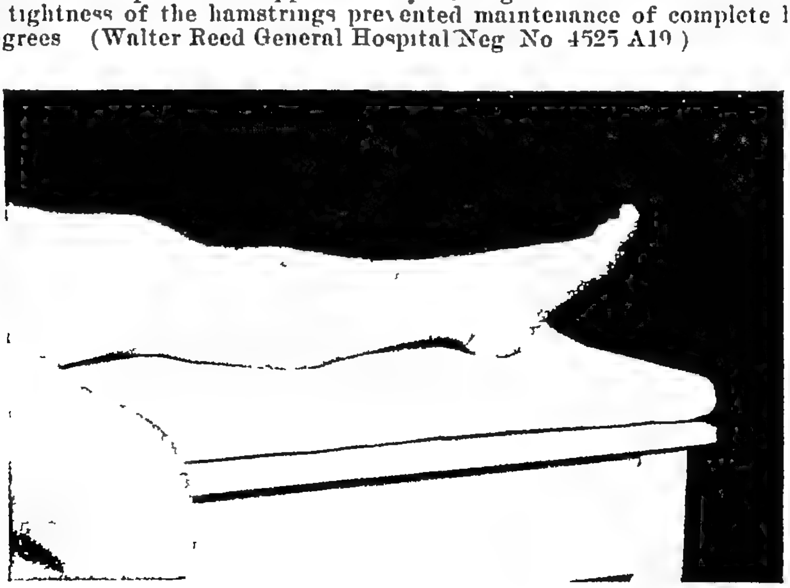


Fig 470—Limitation of flexibility due to gastrocnemius soleus tightness The subject illustrated could dorsiflex the foot only slightly beyond the point shown Note the tightness evident in the Achilles tendon together with the shortening of the extensor hallucis longus and the extensor brevis digitorum (Walter Reed General Hospital Neg No 4342 A14)

the extremity is relaxed, the forearm drops in the position of flexion as shown in the illustration Observe also that the flatness of the lumbar spine is lost, although the individual was making every effort to maintain the position of lumbar contact with the plinth surface

2 *Tightness of the hip flexor muscles* As shown in Fig 473, with the patient in a supine position and the untested extremity held in full flexion contracture of the hip flexors may easily be detected when he attempts to extend the tested thigh against the plinth Contrast the 35 degrees of hip flexor contracture in the patient illustrated with the obvious ease of full extension of the stump in the patient illustrated in Fig 478

Fig 475—Limitation of general extensibility due to hamstring tightness Inability to extend the leg completely in this subject was due to contracture of the hamstrings *Until this contracture was stretched the patient gained neither more complete extension of the leg nor muscle strength in the quadriceps* (*Walter Reed General Hospital Neg No* 4542-A12)

This procedure is one of the most important of those which should be done Contrary to the experience of others, the author s observation is that varying degrees of hip flexion contractures are seen with *great frequency* when special search is made for this defect At one time in an amputation center in a military hospital during World War II, over 30 per cent of the thigh amputees exhibited measurable contraction of the hip flexors This is a point of more than casual importance, for if the prosthesis is fitted to the individual with a hip flexion contracture, as shown in Fig 474 he will never walk well so long as this condition exists Note the extreme lordosis the clockwise rotation of the pelvis, and the poor postural mechanics of the individual shown in Fig 474 The results of excellent surgery, limb fitting, and physical medicine were fully realized when this deformity was corrected

3 *Hamstring tightness* in the below-knee amputee Fig 475 demonstrates a defect commonly found in many below-knee amputees inability to extend the leg completely Simple quadriceps atrophy is a condition relatively easy to correct, but when this occurs concomitantly with tightness of the hamstrings, increase in strength of the quadriceps through exercise will occur most rapidly when the hamstring tightness has been corrected The tendency toward shortening of the hamstrings can be detected early and corrective measures may be instituted before this condition becomes fixed

Muscle Tests

Importance of the Muscle Examination

It may be assumed that every amputee will become ambulatory as soon as possible It is highly desirable that this be the case, for each day the patient remains at bed rest will prolong convalescence by a disproportionate amount of time, partly by reason of deterioration of the functional efficiency of the musculoskeletal system Evidence of weaknesses in muscular function may be detected early and may be corrected in large measure before the patient becomes ambulatory It is particularly important that this be done insofar as possible, for, with ambulation, muscle and postural strains occur which are considerably in excess of those experienced previously by the individual (see Fig 490)

If the patient is to learn to use the prosthesis properly, defects in body mechanics must have been corrected before he applies the prosthesis Correctible defects which coexist with early prosthesis training will invariably lead to the establishment of poor walking habits Correction of these defects prior to training in the use of the prosthesis certainly does not guarantee that poor walking habits may not be acquired, but it does eliminate the greatest single cause for them Only by means of muscle tests can one be sure of the need for specific therapeutic exercises

Examination of the Patient

It is desirable to perform these tests with the patient on a plinth in order that the test positions be carried out under standard conditions The necessity for confining the patient to his bed, however, does not in itself justify omission of the examination Muscle examinations performed on bed patients are usually graded approximately 20 per cent too high due to the "assisting' action of the mattress If the values assigned when the patient is tested in bed are arbitrarily reduced by this percentage, a somewhat fairer estimate of the true muscle strength is obtained

Preference in Muscle Testing Procedures

The tests employed are those in standard use Both the method of muscle testing and that of recording the results of the tests should be those to which the operator is accustomed The point to be stressed is that these tests are no different from muscle tests performed under other circumstances For this reason it is not the purpose of this section to provide detailed information regarding these muscle tests, since complete information is available in the standard texts on this subject

With the understanding that the condition of the patient may preclude certain of these tests, the following muscles should be included in the general muscle examination For purposes of illustration subjects were chosen who were wearing their prostheses, however with minor modifications the tests can be adapted to any stage of treatment

the extremity is relaxed, the forearm drops in the position of flexion as shown in the illustration Observe also that the flatness of the lumbar spine is lost, although the individual was making every effort to maintain the position of lumbar contact with the plinth surface

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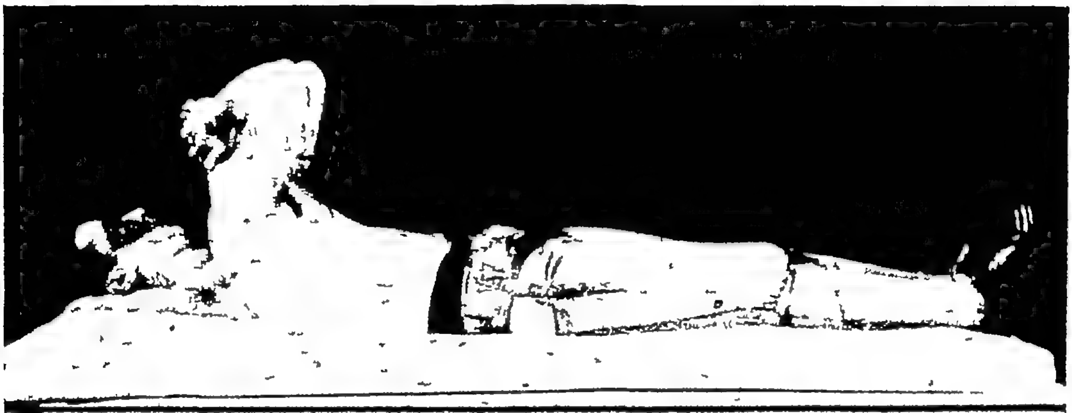
Muscles Customarily Tested

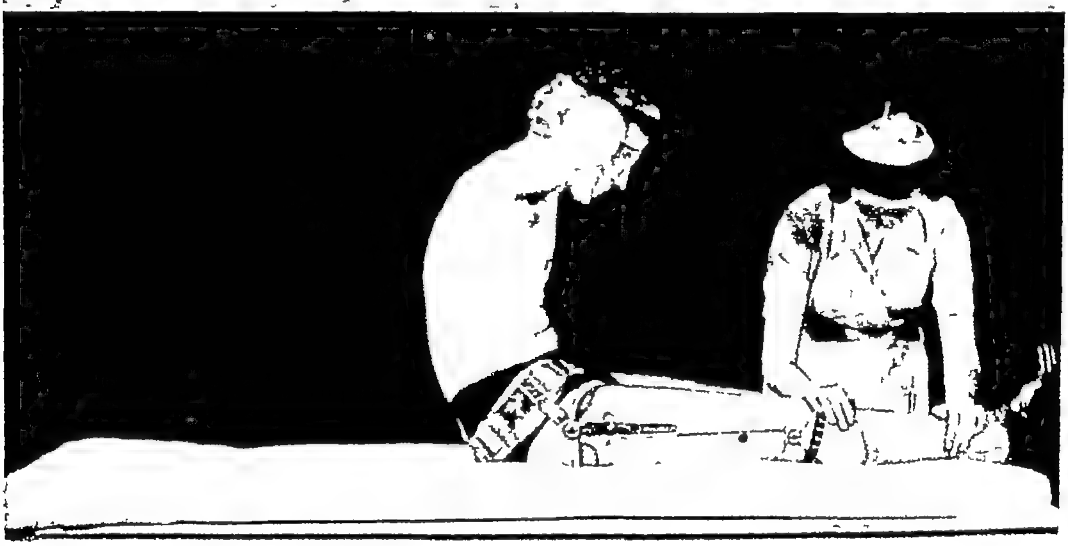
1 "Upper" Anterior Abdominals (rectus abdominis and internal oblique)

a *Purpose* So far as posture is concerned, these muscles are of importance particularly in aiding the hip extensors to maintain the pelvis level and to fix the lower portion of the thorax

b *Position* Supine, leg fully extended, pelvis rolled posteriorly to flatten the lumbar spine against the plinth, hands clasped behind the head

A





B

Fig 476—Muscle tests "Upper" anterior abdominals While holding the lumbar spine flat to the plinth surface, the subject slowly raises the head and shoulders The extent of flexion of the upper trunk, noted in the double exposure photograph of *A* is the maximum possible through action of the anterior abdominal musculature alone With pelvic fixation as shown by anchoring the legs as in *B*, it is then possible to assume the sitting position through action of the hip flexors This illustration demonstrates normal strength of the anterior abdominal musculature (Walter Reed General Hospital Neg No 1525 A13, A11)

c *Test* While maintaining the pelvic roll and the extension of the leg, the patient attempts to raise the head, shoulders, and then the trunk to a sitting position The first portion of this movement is shown in the double exposure photograph of Fig 476,*A* Completion of trunk raising to the full sitting position is accomplished with the examiner anchoring the legs as shown in Fig 476 *B*

Illustrated is the test for normal strength of the rectus abdominis and internal oblique muscles Fig 491 illustrates the beginning position for a test which would be rated 60 per cent (equivalent to a Fair Plus by the Lovett system of grading) The same test completed with the arms folded on the chest would be rated 80 per cent (or Good) Inability to perform the 60 per cent test would be graded according to the distance the head and shoulders could be lifted from the plinth surface (see Fig 491)

2 "LOWER" ANTERIOR ABDOMINALS (rectus abdominis and external oblique)

a *Purpose* As with the "upper" anterior abdominals, the "lower" abdominals are of importance in leveling the pelvis by raising its anterior brim The proper position of the pelvis is a matter of such major importance when walking with the prosthesis that the early seeking out and correction of abnormal pelvic tilt are imperative

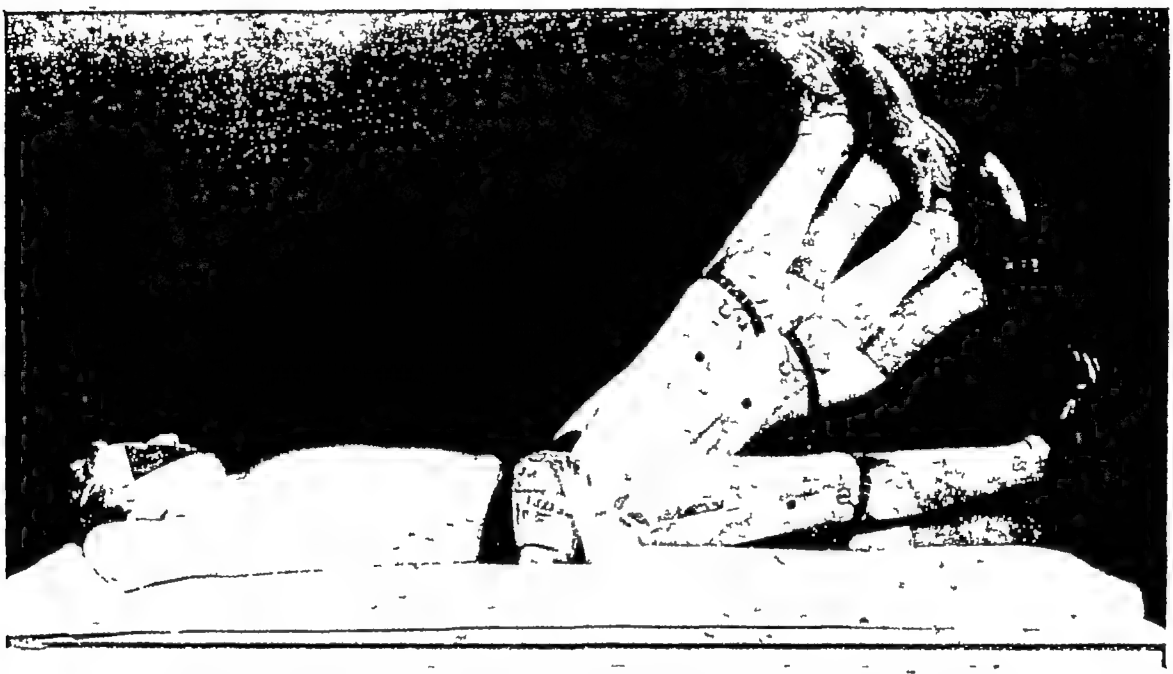


Fig 477 —Muscle tests "Lower" anterior abdominals The subject concentrates on maintaining fixation of the pelvis by the abdominal muscles through flattening of the lumbar spine against the plinth surface As the legs are slowly lowered to the plinth, that point at which fixation of the pelvis is lost and the pelvis tips forward represents the limit of strength of the "lower" anterior abdominal muscles The three positions illustrated are for 60, 80, and 100 per cent muscle strength of the muscles tested (Walter Reed General Hospital Neg No 4525 A8)

b *Position* Supine, hands clasped behind the head (or folded on the chest), pelvis rolled to flatten the lumbar spine against the plinth The examiner flexes the lower extremity to a position of approximately 90 degrees to the trunk

c *Test* Fig 477 illustrates the various phases of this test The examiner withdraws support from the extremity While the patient concentrates on maintaining the lumbar spine flat against the plinth, he slowly lowers the extremity to the surface of the plinth The examiner, by palpation, notes the patient's ability to maintain the lumbar spine flat during this maneuver, the point at which pelvic fixation is lost as the leg descends (i e, when the pelvis begins to tip anteriorly) represents the "breaking" point of the abdominal muscles being tested If the patient is able to maintain pelvic fixation throughout the arc of motion of the legs the lower anterior abdominals are graded as normal or 100 per cent

The triple exposure photograph of Fig 477 illustrates the positions at which 60 per cent (Fair Plus), 80 per cent (Good), and 100 per cent (Normal) rating would be accorded the test, depending on whether pelvic fixation was lost when the leg was at a 60 degree, 40 degree, or 0 degree angle from the plinth respectively

d *Note* The procedure of leg raising itself has nothing to do with the abdominal muscles except in so far as this provides an added weight to the pelvis which the abdominals must resist in order to maintain pelvic fixation As the leg descends, an increasing load is applied to the abdominal musculature

3 Hip Flexors (iliopsoas, chiefly)

a *Purpose* Weakness of the hip flexors as a group is seldom seen However, it is included to insure that all aspects of potential imbalance of the pelvis be investigated

b *Position* Supine, legs extended, arms at side

c *Test* As shown in Fig 478, the extremity is flexed in a neutral position

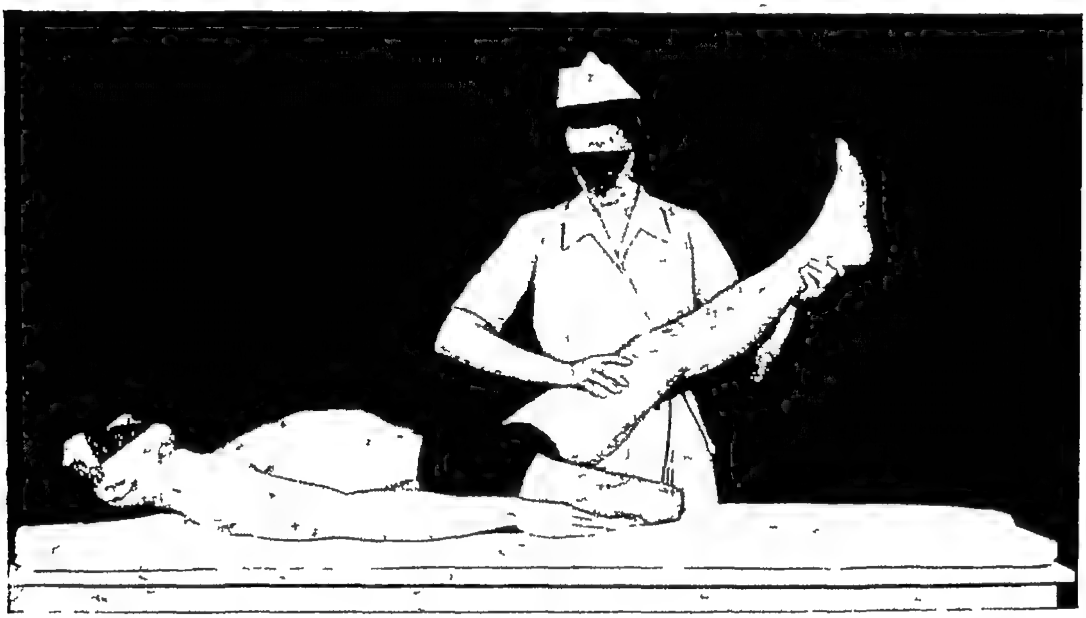


Fig 478—Muscle tests Hip flexors Resistance is applied in a downward, outward direction to the extended extremity as shown in this illustration It is usually necessary to apply pressure simultaneously to the opposite anterior iliac crest to prevent torsion of the pelvis toward the tested side (Walter Reed General Hospital Neg No 4542-A18)

midway between internal and external rotation as the examiner applies resistance in a downward, slightly outward direction The examiner's other (left) hand notes whether the extremity rotates inwardly or outwardly during this procedure to detect sartorius-tensor fascia lata imbalance)

4 Hip Internal Rotators

a *Purpose* Proper balance between the internal and external rotators of the thigh is essential in insuring absence of muscle strain in standing and in gait progression

b *Position* Supine, leg extended, pelvis rolled posteriorly to flatten the lumbar spine, arms at side

c *Test* From a position of external rotation, internal rotation of the extremity is accomplished against resistance supplied by the hands of the examiner in the position shown in Fig 479

5 Hip External Rotators

a *Purpose* As in *4* above

b *Position* Supine, leg extended, pelvis rolled posteriorly, arms at side

c *Test* From a position of slight internal rotation, external rotation of the extremity is accomplished against resistance supplied by the hands of the examiner as shown in Fig 480

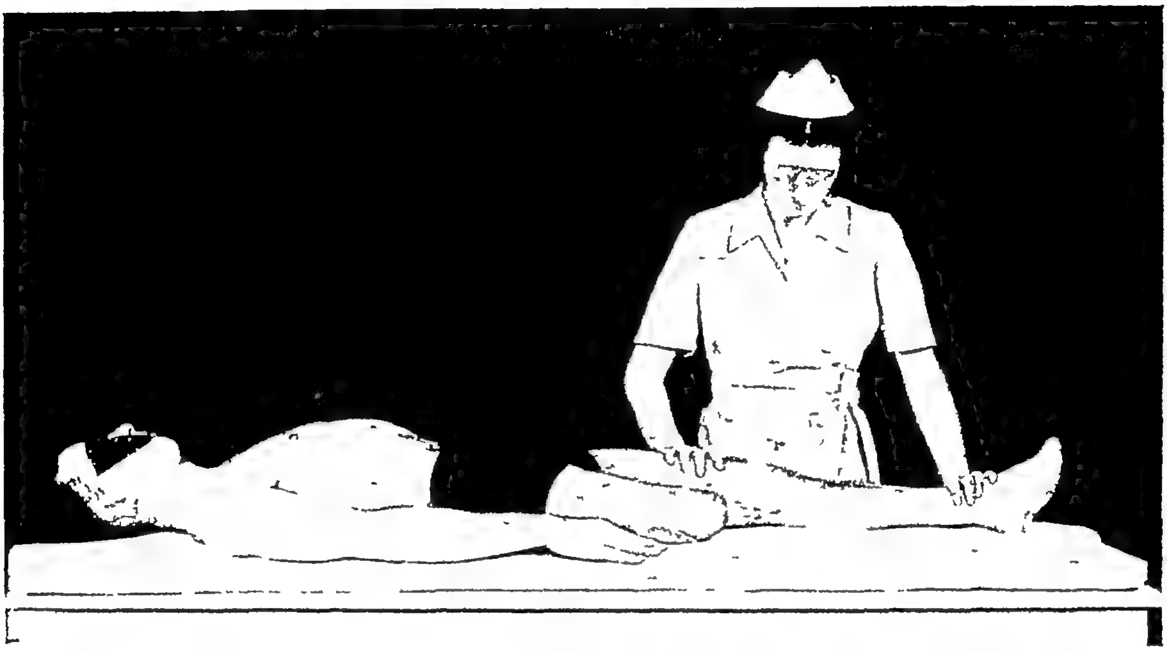


Fig 479—Muscle tests Hip internal rotators From a position of external rotation, the subject internally rotates the extended extremity against the resistance offered by the examiner's hands (Walter Reed General Hospital Neg No 4542-A3)

Fig 480—Muscle tests Hip external rotators From a position of slight internal rotation, the subject externally rotates the extended extremity against the resistance afforded by the examiner's hands (Walter Reed General Hospital Neg No 4542 A17)

6 Posterior Tibial

a *Purpose* As shown in Fig 490, the posterior tibial muscle is subject to marked strain in weight-bearing, as a result of the position the foot must

481

482

Fig 481—Muscle tests Posterior tibial With the foot in a position of inversion and slight plantar flexion, the subject resists the pressure of the examiner's hand which is applying force in a rotatory outward and upward direction (Walter Reed General Hospital Neg No 4542 A10)

Fig 482—Muscle tests Flexor hallucis longus With the foot in a position of slight plantar flexion, the subject strongly flexes the toes as the examiner applies directly vertical pressure to the base of the distal phalanx The other long toe flexors are tested in the same fashion (Walter Reed General Hospital Neg No 4542 A9)

Fig 483—Muscle tests Gluteus medius While the subject maintains the extended extremity in a position of abduction, extension, and external rotation, the examiner applies resistance in a diagonal, downward, inward direction The anterior spines of the ilium must be in a vertical plane during the test (Walter Reed General Hospital Neg No 4525 A17)

assume in standing when the patient subsequently becomes ambulatory Detection and correction of weakness of this muscle prior to ambulation may prevent considerable trouble with the foot and extremity later

b *Position* Supine, foot pulled diagonally downward and inward, the examiner's one hand (the right in Fig 481) palpates the tendon of the muscle, the other (left) hand prepares to resist the position of the foot

c *Test* As shown in Fig 481, as the patient holds his foot in strong inversion and plantar flexion, the examiner attempts to bring the foot to a neutral position

d *Note* Insure that the patient does not flex the toes during the test

7 Flexor Hallucis Longus

a *Purpose* Adequate thrust of the foot as it leaves the ground during forward progression is essential to a smooth gait, such thrust is provided principally by the long toe flexors Inasmuch as the prosthetic foot has no such action, it is the more essential that there be no weakness in the uninvolved foot

b *Position* Supine, leg extended, foot in slight plantar flexion

c *Test* As the patient strongly flexes the terminal phalanx of the great toe, the examiner applies resistance in the direction of extension to this phalanx as is shown in Fig 482

d *Other Toe Flexors* The flexors longus and brevis digitorum for the other toes should be tested for weakness in the same manner

8 Gluteus Medius (posterior fibers)

a *Purpose* As shown in Fig 490, the position of lateral pelvic tilt and adduction of the uninvolved extremity imposes a severe mechanical strain on the lateral pelvic fixators, chief of which is the gluteus medius Weakness of this muscle during subsequent ambulation, particularly with the prosthesis, will result in asymmetry of gait from this source alone Inasmuch as it is extremely difficult to strengthen a weak gluteus medius in the ambulatory individual, it is imperative that weakness of this muscle be detected and corrected in the non-ambulatory or preambulatory stage

b *Position* Side lying, body in straight line, leg extended, thigh carried into complete abduction, slight extension, and slight external rotation

c *Test* While the patient endeavors to maintain the lower extremity in the position shown in Fig 483, the examiner applies resistance to the foot in a downward and slightly inward direction

d *Note* The examiner's other (right) hand not only palpates the tested muscle, but prevents movement of the pelvis from a neutral position and substitution of movement by other muscle groups

9 Hip Abductors (chiefly the tensor fascia lata and anterior portion of gluteus medius)

a *Purpose* The balance between the abductors and adductors of the hip are of importance particularly in determining lateral postural deviations in standing and contribute to stability of the sagittal planes of the body in forward progression

b *Position* Side lying, body in straight line, leg extended thigh slightly internally rotated

c *Test* As shown in Fig 484, while the patient maintains the thigh in its position of slight internal rotation, he abducts and slightly flexes the thigh against the resistance of the examiner's hand which is applied in the direction of adduction and slight extension

10 Hip Adductors

a *Purpose* As in 9 above

b *Position* Side lying (left side for testing left adductors), body in straight line, leg extended, opposite lower extremity held in abduction by the examiner

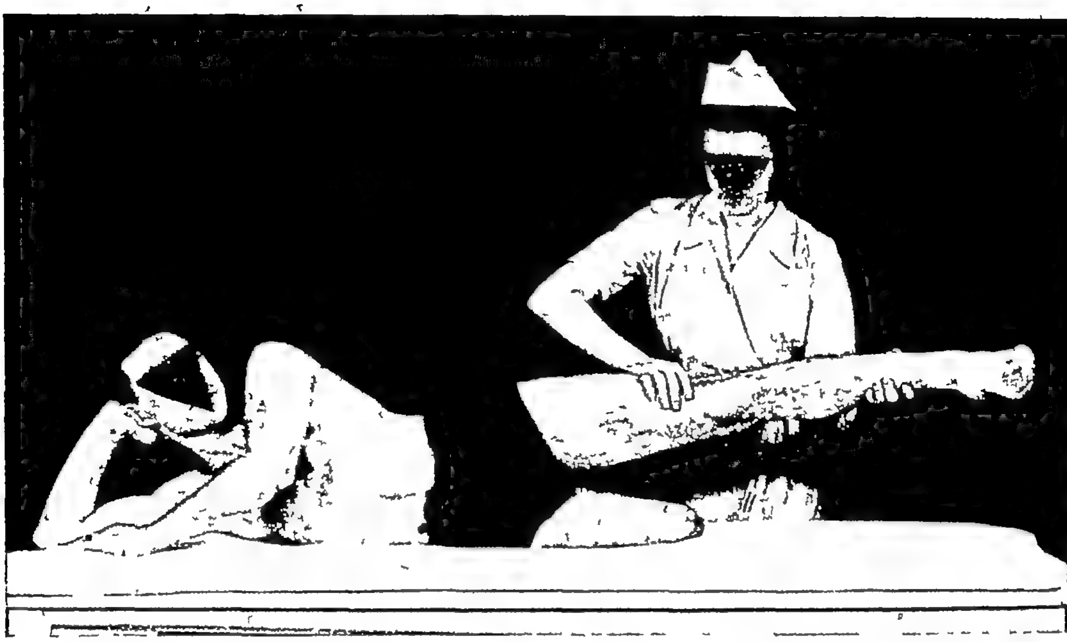


Fig 484.—Muscle tests Hip abductors From a position of abduction of the extremity along a vertical plane, the examiner applies resistance in a directly downward direction The extremity should be abducted further than shown in the illustration (Walter Reed General Hospital Neg No 4542 A6)

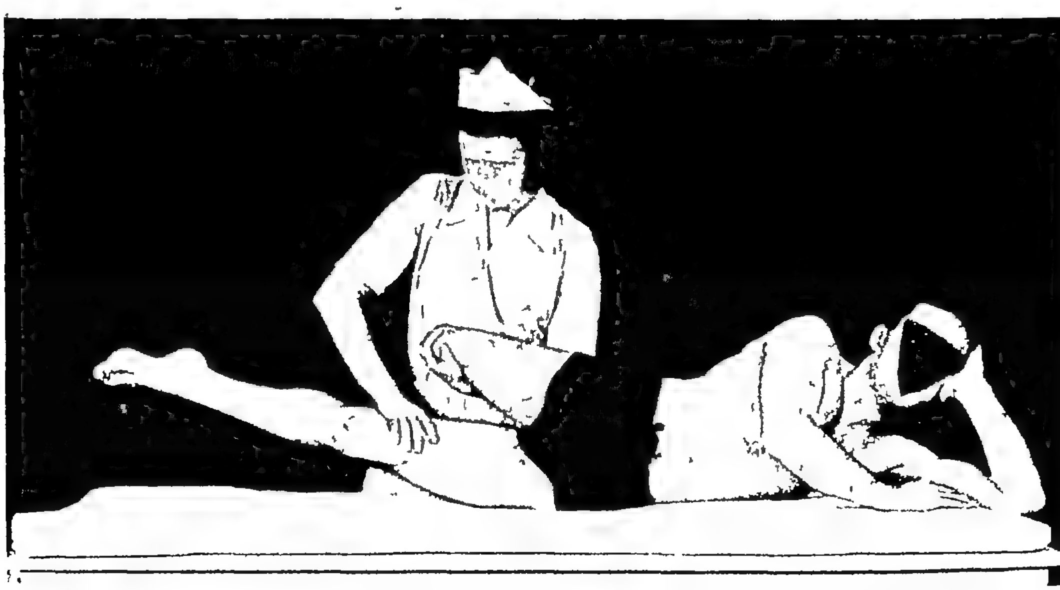


Fig 485—Muscle tests Hip adductors The subject adducts the tested extremity toward the abducted opposite extremity Adduction is accomplished along a vertical plane against the opposing resistance of the examiner's hand (Walter Reed General Hospital Neg No 4542 A4)

c *Test* As shown in Fig 485 the patient adducts the under leg to the upper leg in a direct frontal plane without flexing or extending the thigh, pelvis, or lower back as the examiner provides resistance in the direction of direct abduction

11 Lateral Abdominals

a *Purpose* Varying degrees of abduction of the thigh of the amputation side are fairly common It is of importance to determine whether this is due to the tightness of the lateral abdominals or the hip abductors, since corrective measures are not the same

Fig 486—Muscle tests Lateral abdominals With the body carefully aligned in a straight line, lateral flexion of the upper torso on the pelvis is accomplished by lifting the head and shoulders up in a direct frontal plane The examiner should carefully note the movement of the pelvis and trunk during the test (see text) (Walter Reed General Hospital Neg No 4542 A7)

Fig 487—Muscle tests Gluteus maximus With the leg flexed, the subject extends the thigh in a plane midway between adduction and abduction The examiner applies resistance to the thigh in a directly downward direction (Walter Reed General Hospital Neg No 4542 A6)

b *Position* Side lying (left side for testing the right lateral abdominals), body in straight line, lumbar spine straight through pelvic roll and contraction of the abdominal muscles, hand of under arm clasping opposite shoulder with

elbow lifted from the surface of the plinth, upper arm extended down side with fingers either clenched or positioned in such a way that they cannot assist in the test movement

c *Test* The patient raises the trunk laterally, lifting the under shoulder from the table as shown in Fig 486 Observe carefully the relationship between the lifting of the shoulder, the lower margin of the rib cage, and the lateral iliac crest Weak hip abductors will permit the iliac crest to be pulled toward the lower ribs Weak lateral abdominals will not lift the shoulders clear from the plinth if the pelvis is fixed laterally either by strong abductors or manual fixation

d *Note* The examiner's hands do not assist the test movement, as shown in Fig 486, they merely insure true lateral-motion of the trunk without torsion or other assistive motion,

12 MIDDLE AND LOWER TRAPEZIUS

a *Purpose* These muscles, together with the dorsal sacrospinalis, through their action in providing scapular fixation and extension of the upper back, are of importance in maintenance of good posture However, weakness of these muscles is so frequently associated with contracture of the pectorals and upper anterior abdominal muscles that muscle tests are of less accuracy until the contractures noted have been corrected

b *Position* Prone For the middle trapezius the arm is abducted 90 degrees from the side and is maintained in full external rotation For the lower trapezius, the arm is extended over the head with the forearm pronated

c *Test* The examiner applies resistance to the outstretched forearm along an imaginary line perpendicular to the direction of the fibers of the muscles being tested

13 HIP EXTENSORS (the gluteus maximus in the above-knee amputee)

a *Purpose* For the amputee, strength of the hip extensors is particularly necessary for standing as well as for locomotion Since unusual mechanical strain is imposed on the hip extensors, particularly of the side of the amputation, during locomotion with the prosthesis, and since it is difficult to strengthen these muscles during ambulation, it is important that exercise of these muscles be started early if weakness is found

b *Position* Prone, untested leg extended

c *Test* To differentiate between the action of the gluteus maximus and the hamstrings, as shown in Fig 487, with the knee flexed to eliminate action of the hamstrings, the patient extends the thigh as the examiner offers resistance in a downward direction The leg may then be extended and the ability to extend the thigh against resistance again noted, difference in muscle strength between this and the preceding test may be credited to assistance of the hamstrings

d *Note* Guard against hyperextension of the pelvis on the trunk, adduction or abduction of the thigh, or other motion which tends to substitute for the straight movement of thigh extension

14 HAMSTRINGS

a *Purpose* Strength of the hamstrings is important in posture, particularly in maintaining fixation of the pelvis posteriorly and inferiorly Since anterior pelvic tilt is one of the most persistent of the abnormalities in postural mechanics in the amputee, early correction of hamstring weakness is particularly to be desired

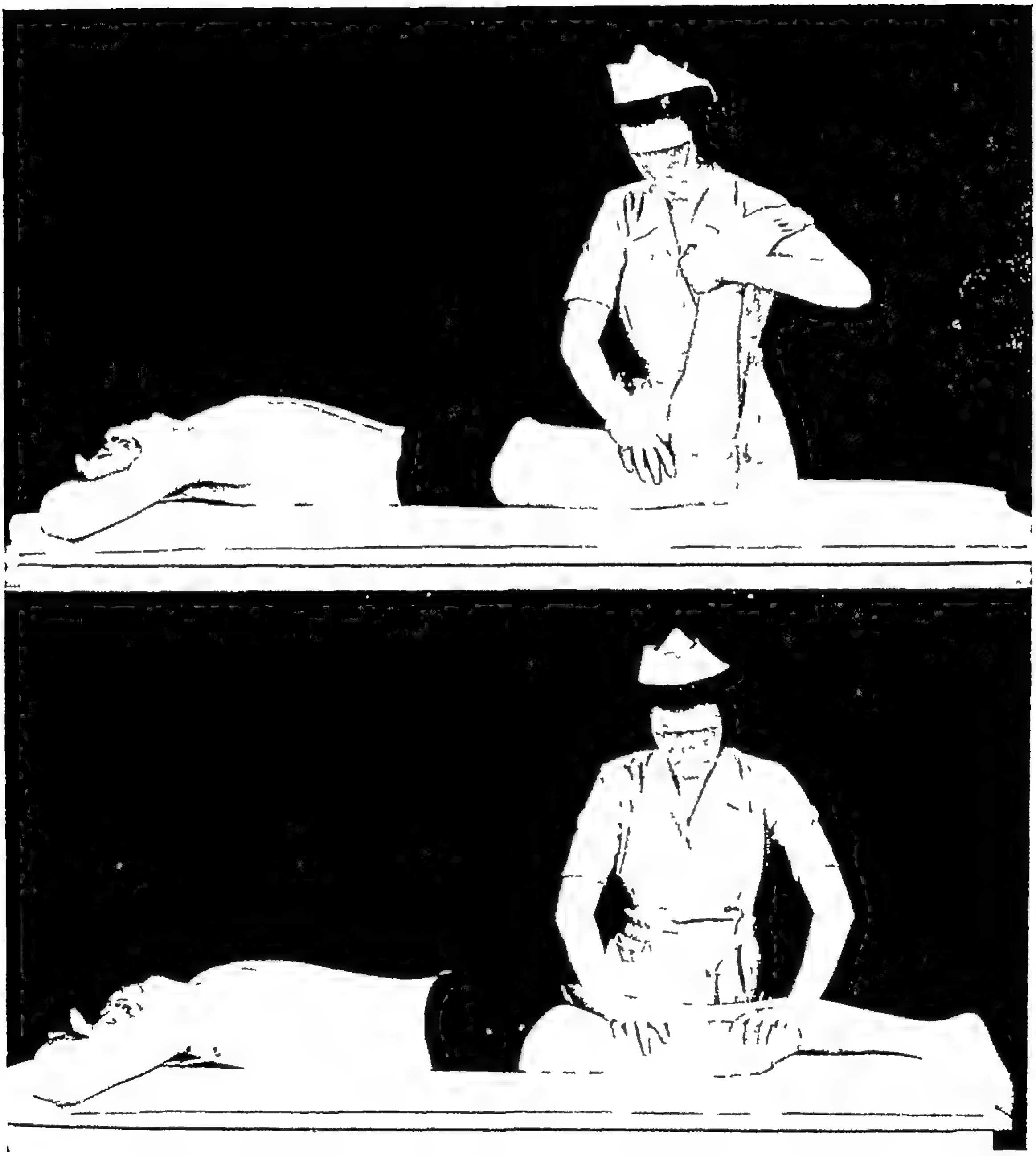
b *Position* Prone, leg flexed to approximately a right angle

c *Test* The patient resists the examiner's efforts to extend the leg as shown in Fig 488, *A*

c *Note* The examiner's free (right) hand palpates the tendons of the inner and outer hamstrings Suspicion of weakness of one or the other should be confirmed by tests of each

e *The Amputation Side* If the insertion of the hamstrings is intact, estimation of hamstring strength of the involved extremity is of importance Since the gastrocnemius muscle is nonfunctional, the hamstrings may be tested with the leg stump in full extension, as shown in Fig 488, *B*, for knee flexion will then be entirely the result of hamstring action

A



B

Fig 488—Muscle tests Hamstrings

A, While the patient strongly flexes the leg, the examiner attempts to extend it Differences between the strength of the inner and outer hamstrings should be further estimated by internal rotation of the leg and applying resistance in a downward and outward direction in the case of the inner hamstrings and the reverse direction for the outer hamstrings

B, If the below knee stump is sufficiently long to be used as a lever, the hamstrings of the stump side may be tested in a similar manner (Walter Reed General Hospital Neg No 4542 AS, 16)

Record of Examination

PART I

POSTURE EXAMINATION

Plumb Line Tests

ANTERIOR POSTERIOR ALIGNMENT

____Normal
____Lordosis
____Forward head
____Pelvis anterior
____Body anterior
____Upper trunk posterior

LATERAL ALIGNMENT

____Normal
____Scoliosis
____Displacement of pelvis
____Displacement of thorax
____Displacement of head

Segmental Alignment

FOOT	____Normal ____Pronated ____Supinated ____Low ant arch ____Low long arch
KNEE	____Normal ____Int rotated ____Ext rotated ____Hyperextended ____Flexed ____Varus ____Valgus ____Tibial torsion
PELVIS	____Normal ____High post iliac spine ____Rotation ____Displacement
LOWER BACK	____Normal ____Lordosis ____Kyphosis ____Flat
UPPER BACK	____Normal ____Kyphosis ____Flat ____Elevated scapula ____Abducted scapula
THORAX	____Normal ____Depressed chest ____Elevated chest ____Rotation
SPINE	____Normal ____Total curve ____Cervical ____Dorsal ____Lumbar
ABDOMEN	____Normal ____Protruding ____Scars ____Hernia
SHOULDERS	____Normal ____High ____Low ____Forward ____Back
HEAD	____Normal ____Forward ____Backward ____Hyperextended

PART II

TESTS FOR FLEXIBILITY, EXTENSIBILITY, AND CONTRACTURES

Forward Flexibility

____Normal ____Limitation: ____Back ____Hamstring ____Gastrocnemius soleus

General Extensibility

____Normal ____Limitation: ____Pectoral ____Hip flexor

Trunk Lateral Flexion

____Normal ____Limitation: ____Right ____Left

Hip Abductors

____Normal ____Limitation: ____Right ____Left

Muscle Tests

Left		Right
	"Upper" abdominals	
	"Lower" abdominals	
	Hip flexors	
	Hip int. rotators	
	Hip ext rotators	
	Posterior tibial	
	Long toe flexors	
	Gluteus medius	
	Hip adductors	
	Lateral abdominals	
	Middle trapezius	
	Lower trapezius	
	Hip extensors	
	Hamstrings	
	Quadriceps	

15 QUADRICEPS

a *Purpose* Weakness of the leg extensors in the amputee is a severe handicap More than its usual share of mechanical strain must be assumed by the quadriceps in ambulation As is true with so many weight-bearing muscles, if the ambulatory activities of the individual are sufficient to weaken the quadriceps, exercise plus such ambulatory activities do not strengthen that group It is necessary to seek out and correct these defects prior to weight-bearing

b *Position* Sitting, leg extended completely over edge of plinth

c *Test* As illustrated in Fig 489, the examiner applies force vertically in the direction of flexion of the leg as the patient maintains the position of extension

d *Note* The normal quadriceps should lock the leg in extension so strongly that the examiner should be able to lift the weight of the body using the region of the knee joint as a fulcrum The case illustrated shows inability to maintain the final 20 degrees of leg extension against slight resistance

Fig 489—Muscle tests Quadriceps With the leg fully extended, the examiner applies resistance to the leg in a directly downward direction (Walter Reed General Hospital Neg No 4542-A11)

MASSAGE

Massage in the treatment of amputations is frequently dismissed with the casual comment that it is contraindicated, that it does more harm than good, that it serves only to irritate the nerve endings, or that it must be prescribed on an individual basis Such unqualified statements betray an imperfect understanding on the part of their authors of the medical prescription of massage

A procedure which in itself is harmful is one indeed which is contraindicated However, if it is harmful solely by virtue of its having been improperly

prescribed, the error is then to be charged to the physician, not to the method. Similarly, a procedure which produces both good and poor results invites suspicion of its improper prescription in those instances wherein harm resulted from its application.

Irritation of nerve endings is a vague phrase apparently having its origin in the experience of the English surgeons that neuroma formation at the amputation site is a common occurrence. In this country, painful neuroma formation is a rare occurrence. On the other hand, amputations which are painful are frequently encountered; the ease with which such pain may often be controlled by physical measures in the form of thermotherapy, hydrotherapy, procaine ion transfer, or simple vascular exercises would indicate that in many instances the basic cause for the pain is vascular rather than neural. The blanket condemnation of a procedure on the grounds that it will aggravate a rarely occurring condition seems particularly ill considered when the procedure is of known value when properly prescribed.

The criticism that massage must be prescribed on an individual basis is well taken. It is sincerely hoped that no facility in physical medicine will be employed unless it is specifically indicated and prescribed on an individual basis. However, the dismissal of a procedure as applicable only on a prescription basis by no means lessens the need for comments regarding it.

The single prime contraindication to massage of the amputation stump is the presence of infection. The same contraindication applies to massage wherever it might otherwise be employed, hence this is nothing peculiar to the amputation problem. Whenever the physician is certain that infection is absent, and the usual indications for massage exist, massage may then be properly prescribed and carried out with benefit to the patient. It should be remembered, however, that the circulatory efficiency of the distal portion of the stump is less than in the normal extremity. The presence of secondary infection, which in varying degrees is almost universal in the tissue immediately adjacent to the site of the incision, constitutes a potential threat to the security of healing. This is especially true if the ill-timed prescription of massage spreads the bacteria beyond the imperfectly erected barrier of tissue immunity in the early postsurgical period. For this reason conservatism dictates avoidance of massage for at least three weeks following surgery, even in the presence of apparent healing per primam.

In the late postsurgical period or preprosthetic period, massage is of definite value in improving the vascular dynamics, in improving the tone of the skin and subcutaneous tissue, in minimizing adherence of the surgical scar to the underlying structures, in minimizing fibrosis in the intramuscular and interfascial tissue planes, and in promoting a subjective sense of well-being in the stump.

Massage is most effectively employed after preliminary thermotherapy. Movements are always in the direction of the venous return and are of such depth and force as to be comfortable to the patient. Friction massage to the scar for the purpose of freeing it from an adherent fibrosis to the underlying periosteal tissue should be performed gently, stretching but never rupturing the binding fibrous strands.

Following removal of the bandage, particularly when the bandage has been applied for shrinking purposes, the skin is noted to be relatively ischemic and a certain degree of cutaneous edema is present. The immediate reapplication of the bandage under tension contributes further to these evidences of poor vascularity. The results of this are manifest in a soft, atonic skin which resists

infection poorly, which stretches easily yet is not elastic, and which tends to become redundant Massage, even in the form of simple "rubbing" of the skin by the patient, prior to rebandaging will markedly minimize these undesirable signs

Forceful, heavy massage is poorly tolerated and may aggravate a latent thrombophlebitis or other infectious focus which might not otherwise become clinically active

The physician and physical therapist alike must be on guard for the development of signs of inflammation in the stump during the period when massage is employed The appearance of local areas of heat in the soft tissue or of drainage from the incision, the presence of folliculitis, or the occurrence of unexplained pain in the stump ordinarily call for prompt cessation of massage until this infection subsides It should be borne in mind that, while massage does not cause infection, it may activate foci of infection in the stump and will definitely spread infections beyond the bounds within which local tissue immunity would ordinarily confine them

THERAPEUTIC EXERCISE

Introduction

The purpose of this section is to provide certain general information regarding therapeutic exercise It is intended to demonstrate the application of these principles of therapeutic exercise in the amputee, not to develop these principles further nor to discuss them in detail

While the term therapeutic exercise legitimately should be restricted to those exercises which are properly designed to correct a *known* defect, it is expedient to broaden this concept somewhat to include exercises designed to correct an *anticipated* defect

At the time the individual becomes ambulatory with crutches, it will be found that certain muscles frequently weaken under the strain of weight-bearing Fig 490 illustrates well the effects of postural strain on the musculature of the hip girdle and lower extremity Attention is directed to the evidences of abnormalities in the following muscles and muscle groups weakness of the tibialis posticus, the abductors and external rotators of the right thigh, contractures of the right lateral abdominals, weakness of the left lateral abdominals, and the abduction of the amputation stump (were the pelvis leveled properly) Not shown in the illustration, but present, are weakness of the upper and lower anterior abdominal musculature In certain measure these weaknesses may be anticipated and exercises undertaken so that the muscles involved will be strong when subject to the strain of weight-bearing in the ambulant amputee Of greater importance, however, is the fact too seldom realized that if the ambulatory activities of the individual are sufficient to weaken a muscle group, prescribed exercise, in addition to these activities, cannot but further fatigue the muscle involved However, if the prescribed exercise is begun on the non-ambulant patient, at a time when the muscle is at rest so far as mechanical stress and strain are concerned, then the muscle may easily be strengthened to the point that it will not weaken significantly when subject to subsequent weight-bearing strain

Once the need for prescribed exercise is established, as a result of muscle tests, the necessity for continuation of the exercise can be justified only by repetition of these tests from time to time with demonstration of continued need for it If the examination fails to justify the exercise, it should be discontinued

One final general comment concerning therapeutic exercise is the fault too frequently encountered of not insisting that the individual use that muscle group properly once the defect has been corrected. The physiatrist and physical therapist alike must instill into the patient the awareness of correct muscle usage. For example, the patient who performs abdominal exercises for weakness of this muscle group, yet who is permitted to continue the slumped posture characteristic of abdominal weakness, has defeated the entire purpose of the exercise. It is just as legitimate to insist on proper usage of the muscle as it normally functions as to be particular in the manner of performance of the exercise.

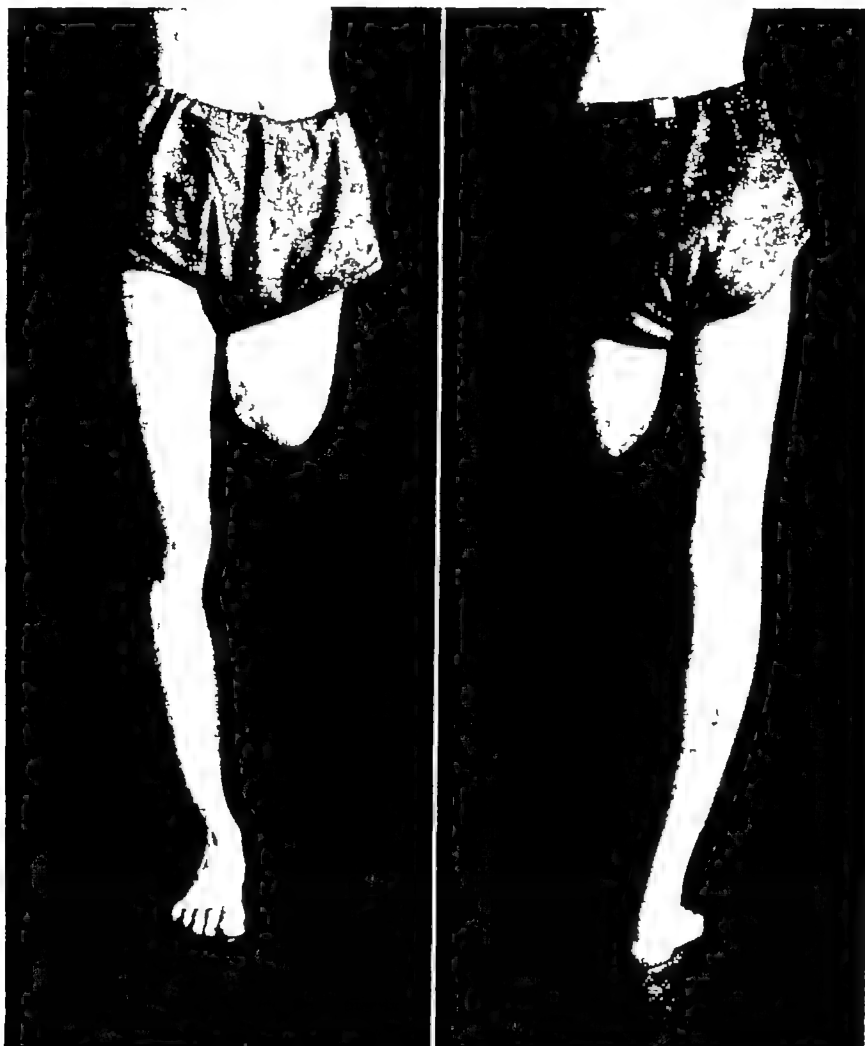


Fig 490.—Static posture strain in the ambulatory amputee. The effects of weight bearing on the single extremity in the ambulatory amputee are evident in the pronation of the foot, torsion of the tibia, internal rotation of the femur, tilt of the pelvis upward on the right and adaptive shortening of the lateral abdominals on the right, compensatory changes on the side of the amputation are reflected in the stretching of the lateral abdominals and abduction of the stump. (Walter Reed General Hospital Neg No 4542 A1, 2.)

With these considerations in mind, the manner of performance of the prescribed exercise is the next problem. It is believed that the best interests of the patient are served only when there is an exact procedure followed in the carrying out of the exercise. The position of the patient should be the most favorable one for the proper performance of the exercise, any deviation from such position

should be permitted only with the full knowledge that the performance of the exercise will be less efficient The patient should thoroughly understand exactly how the exercise is to be performed, and insistence on proper performance should be rigid He should never be permitted to carry out the exercise program without supervision until these stipulations have been met

Specific Exercises

1 **"Upper" Anterior Abdominals** (rectus abdominis and internal oblique)

a Position Supine, arms at side, leg completely extended, pelvis rolled to flatten the lumbar spine

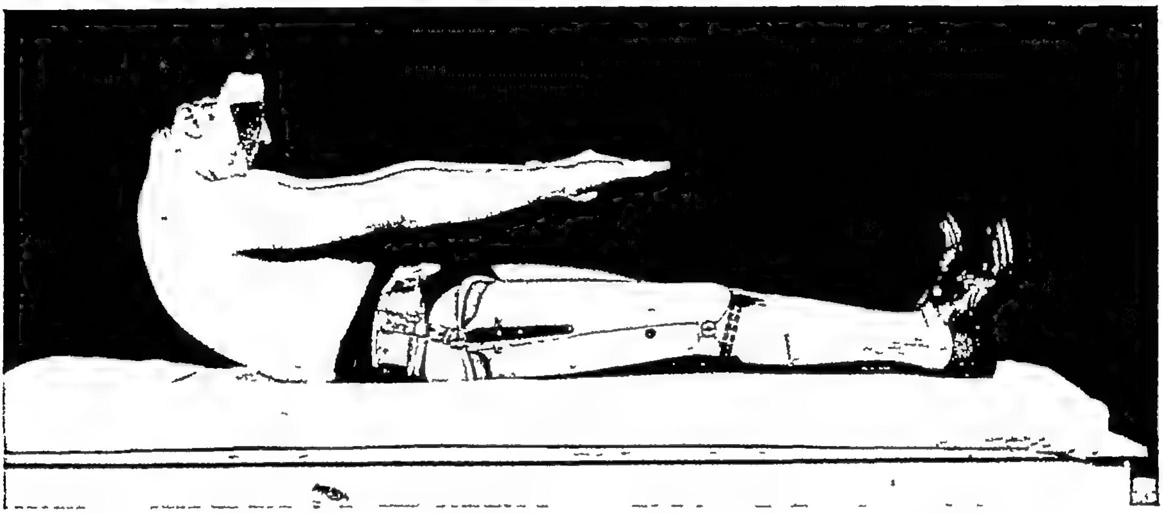


Fig 491—Exercise of the "upper" anterior abdominals While maintaining pelvic roll, the individual reaches forward slowly, raising the head and shoulders from the table to the point shown above The position should be held for 15 to 30 seconds, following which the individual should relax slowly to the initial supine position (Walter Reed General Hospital Neg No 4525 A18)

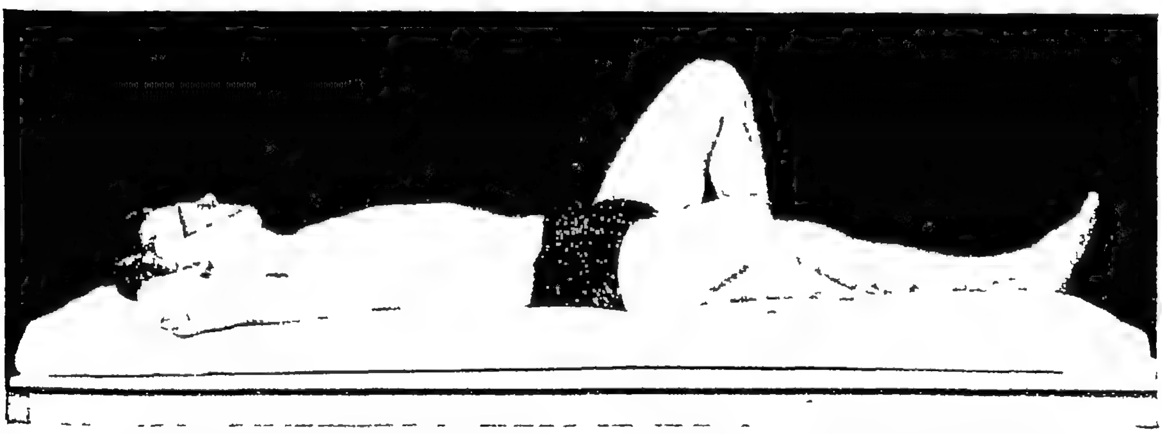


Fig 492—Exercise of the "lower" anterior abdominals With the leg flexed on the thigh and the thigh flexed on the pelvis, the subject flattens the lumbar spine and maintains this position of posterior pelvic tilt by firm contraction of the abdominal musculature Throughout the cycle of slowly sliding the heel down until the leg is completely extended, then sliding it back to the initial position shown in the double exposure photograph, fixation of the pelvis must be maintained The success of this exercise hinges on the ability of the abdominal musculature to maintain pelvic fixation (Walter Reed General Hospital Neg No 4525 A10)

b Instructions While maintaining pelvic roll, the patient slowly reaches forward with the arms, raising his head and shoulders from the exercise table to the extent shown in Fig 491, holds this position without attempting to come to a sitting position, relaxes slowly to initial supine position Progress should

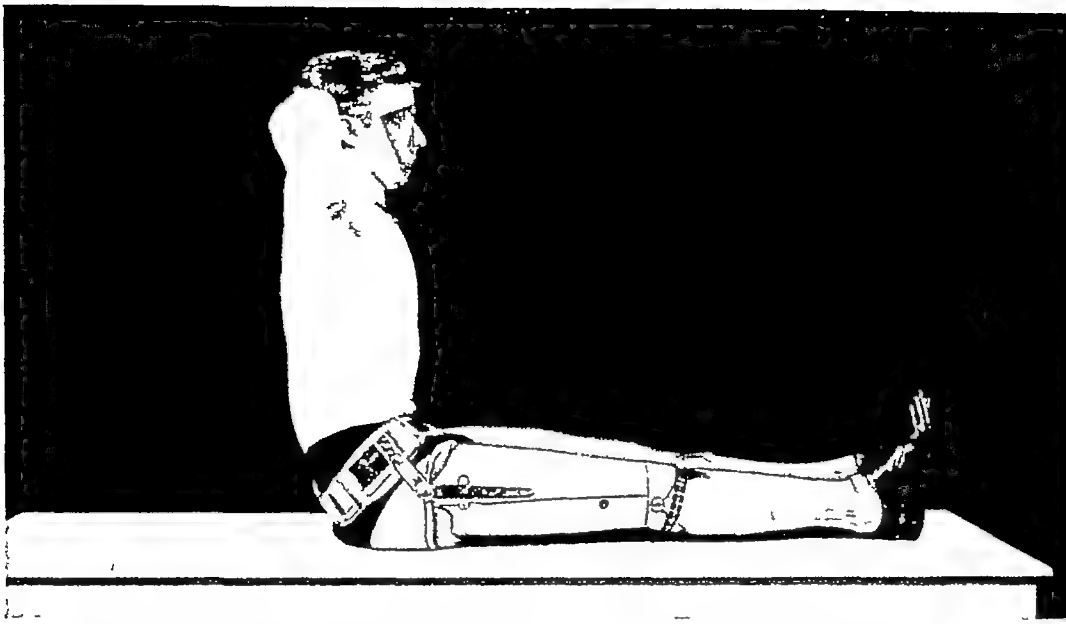


Fig 493—Exercise of the upper back and cervical spine flexors From a sitting position with the buttocks firmly in contact with the wall (not illustrated in this figure), the patient firmly flattens the lumbar spine and attempts to extend the dorsal spine and flex the cervical spine against the wall While the back is held in this flattened position and the hands are beside the head, he presses the elbows backward and downward and backward and upward with a forceful sustained movement Guard against sliding the hands behind the head and thrusting the head forward during this procedure (Walter Reed General Hospital Neg No 4525 A6)

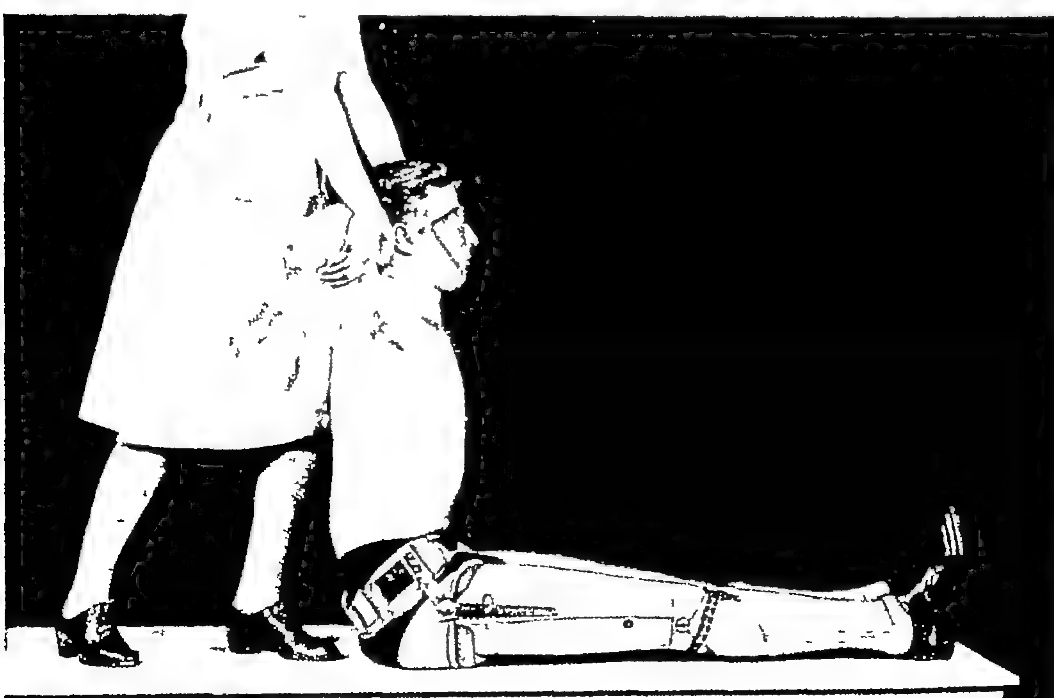


Fig 494—Active assistive pectoral stretching As the patient abducts the elbows, an assistant applies traction to the arms in a backward, upward direction The assistant applies counterpressure to the dorsal region as traction is exerted Traction is continued as long as the patient can actively abduct the elbows (Walter Reed General Hospital Neg No 4525 A5)

be measured in terms of the length of time the head and shoulders can be elevated from the plinth rather than in terms of repetitions of the sequence of movement

2 **"Lower" Anterior Abdominals** (rectus abdominis and external oblique)

a Position Supine, arms beside head (to avoid assisting action during the exercise), knee and thigh flexed, pelvis rolled to flatten the lumbar spine

b Instructions While maintaining pelvic fixation by the abdominal musculature, the leg and thigh are slowly extended by sliding the heel forward until the extremity is completely extended, and are returned to the initial position of flexion by slowly sliding the heel backward as shown in Fig 492 Pelvic fixation is maintained until assumption of the starting position If pelvic fixation is lost so that the pelvis tips forward and contact of the lumbar region with the plinth surface is interrupted, fixation should immediately be regained and the remainder of the exercise sequence completed, do not start the sequence over again but endeavor on the next trial to preserve pelvic fixation past the point where it was previously lost

3 **Upper Back** (flexors of the cervical spine, middle and lower trapezius, and dorsal erector spinae)

a Position Sitting, leg fully extended, back firmly in contact with a solid substance (wall, door frame, or bed post), hands beside head as shown in Fig 493

b Instructions Attempt to flatten the entire spine (cervical spine as well) against the wall while abducting the elbows in a backward and slightly downward direction Progress should be measured in terms of forceful maintenance of this position rather than in terms of number of repetitions

4 **Active Assistive Pectoral Stretching**

a Position Sitting, leg extended, hands beside head, elbows flexed and abducted

b Instructions While an assistant fixes the upper dorsal region, traction is applied to the elbows as the patient abducts them in a backward and slightly upward direction, as shown in Fig 494 Steady forceful traction should be maintained so long as the patient can actively abduct the elbows Relax Repeat

5 **Active Assistive Hip Flexor Stretching**

A *Physical Assistance* Whenever possible, this is the procedure of choice in decreasing hip flexion contractures Fig 495 illustrates the special exercise frame together with the proper positioning of the patient

a Position Sitting, leg fully extended, lumbar spine *flat* against the exercise frame and further fixed by a broad belt as shown in Fig 495

b Instructions Traction is applied to the stump in the directions of extension and adduction so that the thigh is extended in a straight anteroposterior or sagittal plane Weights are added in two pound increments until the patient feels that the hip flexors are relaxed Traction is maintained for a fifteen-minute period Intermittently during this time, the patient should strive to extend the stump further by active contraction of the hip extensors The use of infrared heat during this time facilitates the stretching process and minimizes the muscular and tendinous discomfort which otherwise results early in the course of this exercise

c Note (1) Patients commonly complain of a feeling of discomfort in the groin and anterior part of the thigh subsequent to this exercise It is well to

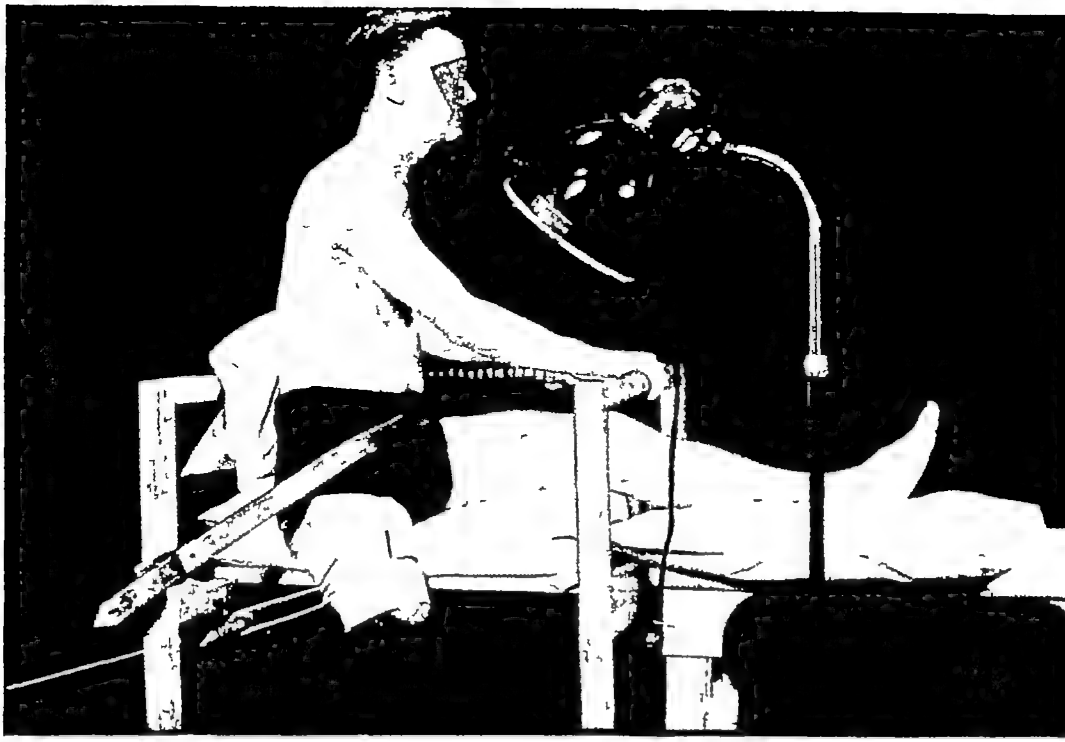


Fig 495—Stretching of hip flexor tightness by traction While the pelvis is fixed by extension of the normal leg, by flattening the lumbar region against the exercise frame, and by the belt around the pelvis in the manner illustrated, traction on the stump is exerted in the direction of extension and adduction Sufficient weight should be used for traction to fatigue the hip flexors The infrared lamp facilitates relaxation of the tight musculature (Walter Reed General Hospital Neg No 4525 A15)

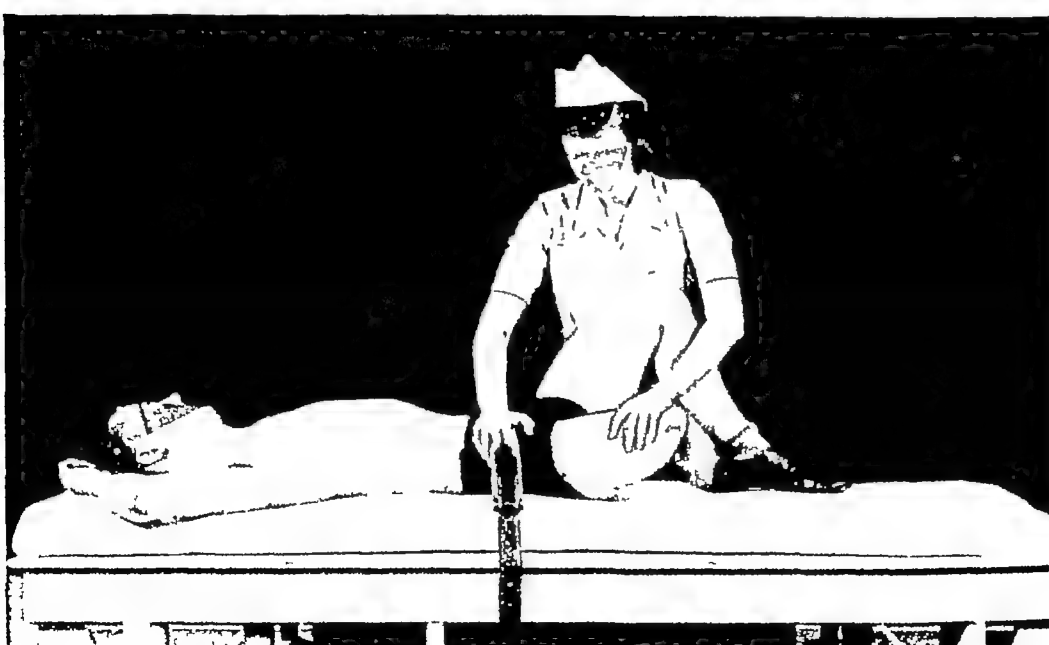


Fig 496—Stretching of hip flexor tightness by manual pressure While fixation of the pelvis is maintained by the broad leather belt, an assistant provides firm, progressively increasing pressure on the stump and anterior crest of the ilium The maximum pressure is maintained for a short period and is succeeded by slow relaxation Pressure is more forceful than indicated in the illustration and the assistant stands on the side of the amputation (Walter Reed General Hospital Neg No 4525 A11)

advise the patient in advance of the probable development of this symptom in order to minimize the apprehension which otherwise would occur. Those patients in whom vascular disease is present should be carefully watched early in the course of this procedure lest overstretching of the contracture further develop the basic vascular pathology.

(2) Sufficient weight should be employed to fatigue the hip flexors so that moderate continuous stretching can then be exerted against the excessive fibrous tissue present in them. Less than fatiguing weights serve only as a stretch stimulus to the development of increased tone in that muscle; more than this weight may rupture muscle fibers, which will lead to increased contracture and disability.

B. *Manual Assistance.* Whenever it is not possible to use the exercise frame or a suitable substitute for it, manual stretching of the contracted hip flexors must be resorted to. Fig. 496 demonstrates the general features of this exercise although for illustrative purposes certain of the details were modified.

a. Position. Supine, unaffected extremity flexed and held on the abdomen, amputation stump extended. A broad belt fixes the pelvis to the plinth. The assistant stands on the side of the amputation facing the patient.

b. Directions. The assistant places one hand on the anterior iliac crest of the amputation side, the other on the anterior surface of the distal portion of the stump. His position should be sufficiently above the patient so that continuous moderate downward pressure can be exerted on both hands without undue fatigue to the operator. Pressure is exerted, gradually at first, until a constant state is attained and is maintained at this steady state for several minutes. Concurrently with the manual pressure, as the stump reaches its limit of extension, the hip extensors of that side should actively contract in an effort to extend the thigh still further. Pressure is then diminished, a relaxation period is afforded, and the cycle is repeated.

C. *Comment.* Specifically to be guarded against is the development of any degree of forward pelvic tilt or lordosis; otherwise, the contracture is not stretched because of closer approximation of the origin and insertion of the psoas muscles in the position of lordosis. For the same reason, active contraction of the lower erector spinae muscles is to be avoided.

It is believed that hip extension exercises should not be emphasized so long as more than 15 degrees of hip flexion contracture exists. Experience has shown that the hip extensors of the stump side can be strengthened with far greater facility when the thigh can be extended to within 15 degrees of complete extension.

6. **Hip Extensors** (gluteus maximus in the thigh amputee).

a. Position. The same type of exercise frame and position of the patient should be employed as illustrated in Fig. 495 with the exception that the weights are suspended anteriorly to the extremity.

b. Directions. The line of pull of the weights should be in the direction of flexion and adduction of the stump so that active exercise is accomplished in the direction of extension and abduction. Weights should be added to the point of fatigue of the muscle since progress is measured in terms of increased power in extension, not by the number of repetitions accomplished.

7. **Quadriceps** (for the below-knee amputee).

a. Apparatus. The use of heavy resistance exercises for the development of the quadriceps is so superior to other types of exercise that this principle should be adopted whenever possible. For support of the weights a long-leg caliper brace may be modified as shown in Fig. 497.

b Position Sitting, leg flexed over the edge of the exercise table, the cuffs of the modified brace encircling the thigh and leg snugly but not tightly

c Instructions Beginning with light weights, a progressively increasing load is applied to the quadriceps in accordance with the principles of heavy resistance-low repetition exercise Emphasis is particularly placed on increasing quadriceps strength within the last 20 degrees of leg extension

d Comment Obviously, the individual still bedfast cannot engage in this type of exercise Static quadriceps exercises, active leg extension against gravity, and such other exercises as can be devised for employment in the non-ambulatory stage should, of course, be pushed to the limit of their indication Unless medical reasons contraindicate their employment, heavy resistance exercises are recommended for the ambulatory patient

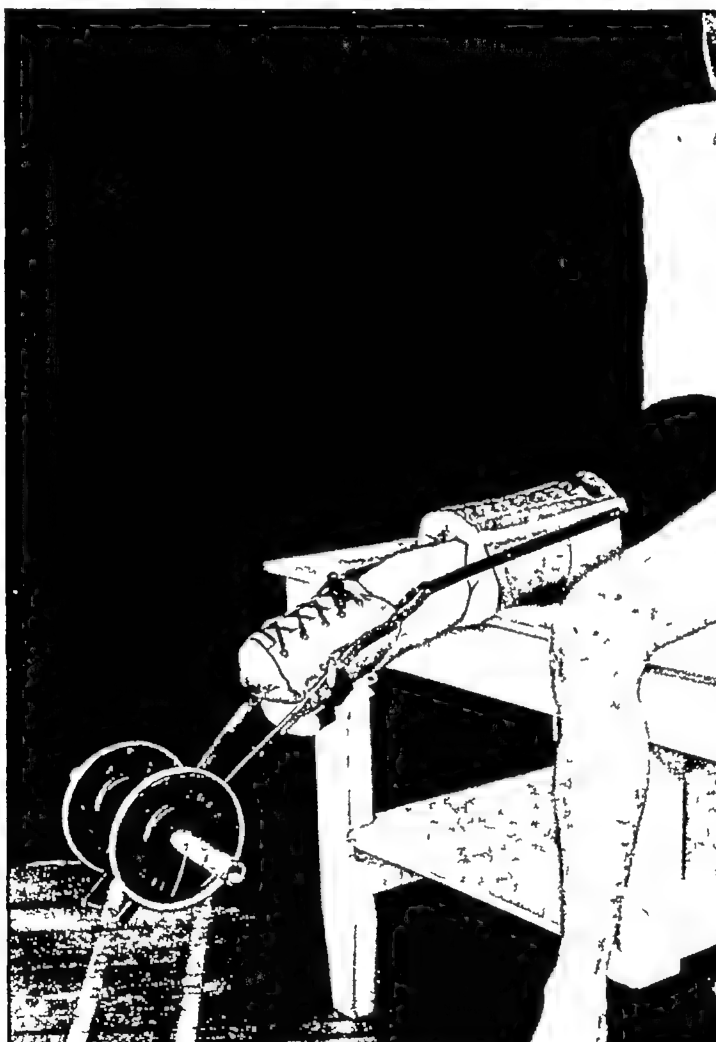


Fig 497—Exercise of the quadriceps Illustrated is the adaptation of a long leg caliper brace for heavy resistance exercise of the quadriceps The weights may be added according to the progression characteristic of heavy resistance low repetition exercises. Be sure that the crest of the tibia is well padded during these exercises (Walter Reed General Hospital Neg No 4542 A13)

8 **Gluteus Medius**

a Position Side lying, extremity to be exercised up, with extremity, pelvis, and trunk in a straight line

b Instructions While maintaining the body alignment, the patient strongly abducts the extended lower extremity as shown in Fig 483 At the extreme limit of abduction, the extremity is externally rotated without turning the pelvis Resistance may be supplied by an assistant throughout the range of motion

9 **Foot Exercises** (anterior and posterior tibial long and short toe flexors lumbricales)

a Position Any position so long as the foot is relaxed

b Instructions This exercise is composed of two movements Strongly pull the forefoot down and in, then up and in Simultaneous with the movement in plantar flexion and inversion, strongly flex all toes Hold the toes in strong flexion as the foot is dorsiflexed and inverted Relax Repeat

Fig 498—Balancing exercise For the unilateral amputee, balancing on the uninvolved extremity before a posture training mirror is valuable in promoting balance, coordination, and posture correction and as an exercise for the foot, thigh, and hip girdle musculature (Walter Reed General Hospital Neg No 4672-2)

10 **Postural and Balancing Exercises** (in the unilateral amputee)

a Purpose As a late preprosthesis exercise, it is frequently of value to improve postural balance further This exercise can be made as strenuous as desired by the degree of flexion of the knee

b Position Fully erect, posture checked for correct position of pelvis, abdomen, chest, and head, arms extended forward (for purposes of aiding bal-

ance) Support may be used until the exercise is performed, at which time the patient should balance on the one foot

c Instructions While maintaining the corrected postural balance, the patient does a knee bend as shown in Fig 498, holds the knee bent position for a few seconds, then resumes the erect posture The exercise is progressed by increasing the depth of knee bend as well as the number of repetitions when that degree of knee bend has been achieved which is the maximum consistent with recovery of the erect posture

d Comment This is an excellent exercise when there is no weakness of the gluteus medius of the uninvolved leg It serves to strengthen further the quadriceps and the musculature which stabilizes the hip It has the added advantage of instilling confidence in the patient in the ability of the uninvolved extremity to support him in many phases of his activities

11 **Vascular Exercises** The functional efficiency of the vascular system in the amputated extremity may be increased considerably by employing postural exercises of the Buerger type Such exercises are of particular benefit when employed following a period of ambulation, but may also be employed in the nonambulant patient

a Position Supine, stump elevated on pillow to approximately 45 degrees of flexion

b Instructions The elevation of the stump is maintained until the skin appears blanched The patient then sits up, extending the thigh over the edge of the plinth or bed and holding the stump in this dependent position until the skin assumes the maximal hyperemia The patient then relaxes in the supine position with the stump in a horizontal plane for several minutes This sequence should be repeated several times at each exercise period Time intervals for each of these procedures is purposely omitted The effects noted are the results to be sought for and the time required to produce them varies from patient to patient

c The above instructions apply primarily to the above-knee amputee The below-knee amputee seldom needs exercises of this type However, the circulation to the stump may be improved with simple flexion and extension of the knee, repeated many times with the stump in first an elevated then a dependent position

Recapitulation

The basic tenets of therapeutic exercise in the amputee may be summarized as follows

1 An accurate knowledge of specific muscle weaknesses and contractures based on examination of the body mechanics of that individual

2 Proper exercise positions

3 Proper instruction in and supervision of the exercise

4 Avoidance of other exercises involving antagonists of weak muscle until muscle balance has been restored

5 Discontinuance of the specific exercises when need for them disappears

6 Insistence of the proper use of the formerly weakened muscle following restoration of muscle balance

BANDAGING

General

Bandaging of the stump is a procedure rather universally recognized to be of value Beyond the general notation that bandaging is useful in reducing

edema of the stump and assists in its selective shrinkage, directions regarding the indications, contraindications, and the usual details incident to the prescription of any therapeutic procedure are in general left to the discretion of the physician or physical therapist While individualization of any procedure must take precedence over generalizations, too often it leads to a lack of formulation of a concrete program which is necessary to the success of any treatment Of even greater importance is the lack of emphasis on the improper use of the bandage, with respect both to the manner of its application and to the time of such application in relation to the therapeutic program as a whole The following discussion has been compiled with the purpose in mind of outlining a general program for bandaging

Types and Properties of Bandages

Before the bandage is to be applied to the stump, something should be known about the physical properties of the bandage being employed In general there are three types of bandage employed for this purpose

1 The Ace-type bandage This bandage possesses elasticity without the incorporation of rubber into its weave The elastic properties are due solely to the twist and the weave of the cotton fibers comprising the fabric Residual elasticity is minimal so that when the bandage is stretched, as when it is applied, it tends to return only part way to the original position This property constitutes both an advantage and disadvantage It is advantageous because it is relatively safe in use, it is relatively difficult to overcompress the soft tissue of the stump The disadvantage is that the bandage must be laundered between applications to restore its elasticity, otherwise, if it is applied in a stretched (and inelastic) condition, it is more likely than not to result in a constricting and not compressing effect This bandage is the one employed most extensively

2 The rubber-containing cotton bandage Similar in appearance to the above bandage, this type incorporates rubber strands into the fabric composing it The rubber content eliminates the defect of loss of elasticity of the all-cotton bandage This is an excellent bandage when applied properly, but it is so often applied improperly that poor and untoward results are frequently noted when it is used

3 The English crepe bandage This bandage is similar to the Ace-type bandage in that it contains no rubber and depends on its peculiar patternless weave for its elasticity Unlike the Ace-type bandage, its elasticity is not appreciably reduced by stretching so that it may be applied repeatedly without impairment of its resilience Also, unlike the Ace-type bandage it is applied to the stump in a position of maximum extension or stretch The English recommend that the same bandage be reapplied to the stump several times daily, this cannot be done with an Ace-type bandage unless a freshly laundered one is used for each such application

The size of the stump is the determining factor in selecting the width of the bandage employed Leg, or below-knee, stumps are satisfactorily bandaged with bandages 3 or 4 inches in width, the larger widths being used for the larger, heavier stumps Thigh stumps may be bandaged with bandages either 4 or 6 inches in width, the larger width being employed for the heavier stump The bandage should be large enough to cover the end of the stump, as shown in Fig 499, *a*, without projecting to form "dog ears" when the subsequent recurrents are brought over it In the lengths in which bandages are supplied commercially it is usually necessary to place two bandages end to end to obtain sufficient length to bandage the thigh stump completely

Laundering Care of Bandage

The laundering care of the bandage is important. Bandages cannot be laundered with routine hospital laundry since standard laundry soap is strongly alkaline in reaction. A soap solution which has a pH greater than 10 will significantly deteriorate the cotton (and rubber) fibers of the bandage. If the bandages are processed through the mangle, all elasticity is removed from the bandage and it becomes totally valueless as a compressing agent. Experience has shown the wisdom of laundering these bandages with a neutral soap (Ivory or its equivalent) in warm water, rinsing the bandages in at least three separate rinses to remove all traces of soap, and drying the bandages on horizontal racks or spread in a flat position. Specifically to be guarded against are hasty rinsing which does not completely remove the soap, hanging the bandages up in a vertical position to dry whereby the bandage weight and water content stretches all elastic qualities from the bandage, and tumbling the bandages dry, a procedure which produces multiple wrinkles in the bandage surface and interferes with its proper smooth application to the stump.

Indications for Bandaging

1. To hold an indicated dressing in place. This relatively minor use of the bandage is mentioned because of its superiority over the simple gauze bandage in holding a dressing, medicated or otherwise, in one place. It is quite possible to apply the bandage under so little tension that there is no interference with circulation, yet the dressing beneath it does not shift with movement or change of position.

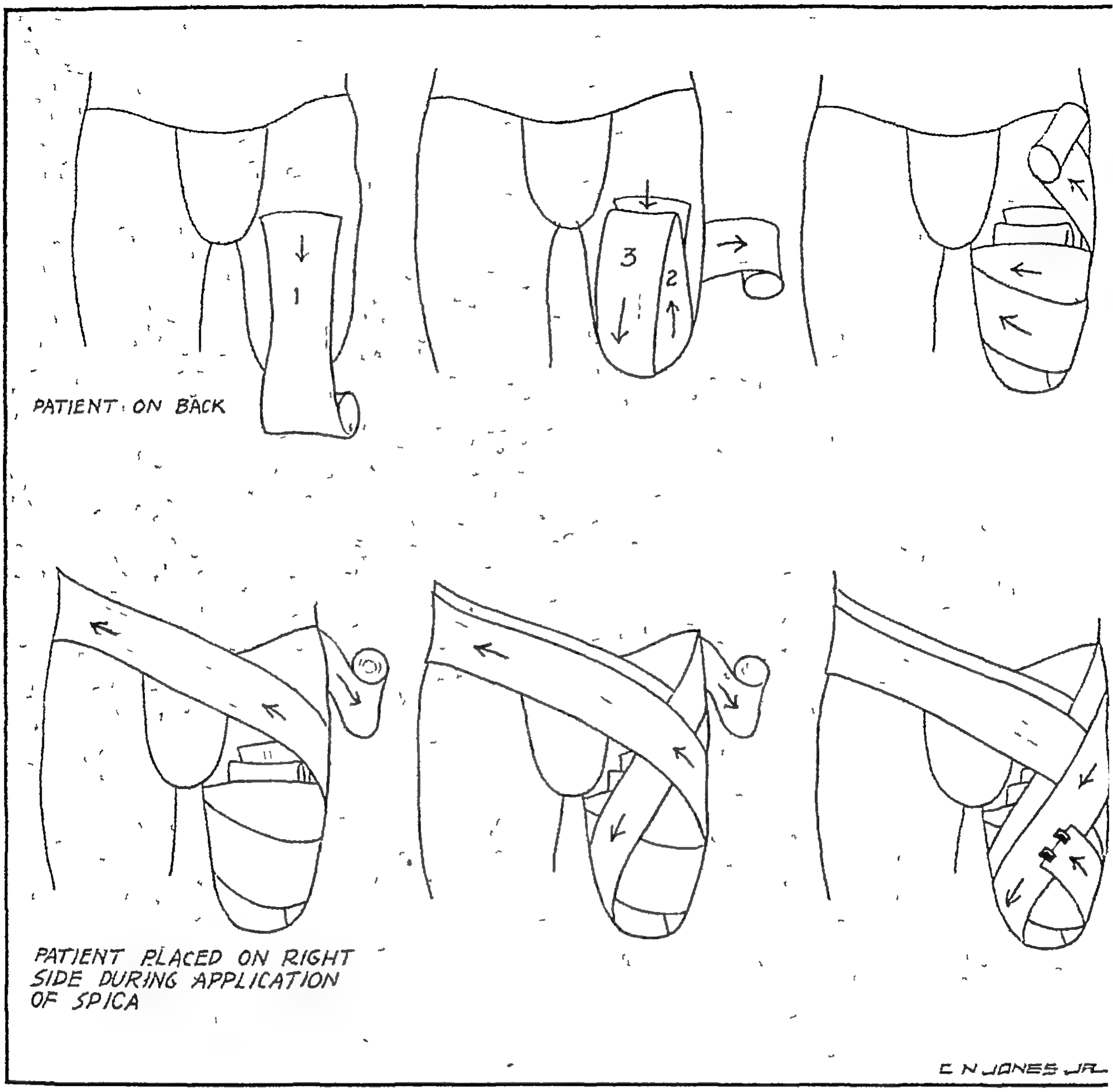
2. As support for the soft tissue. During the time the stump is unhealed and for the first four to six weeks following revision of the stump, or for an equal period of time after primary amputation, the efficiency of the vascular system of the stump is usually markedly impaired. Interstitial fluid accumulates to the extent that the stump feels full or swollen, a sensation disagreeable in the extreme to many patients. Ambulation, with the stump in a dependent position, further aggravates this defect. External support to the soft tissue, in the form of a properly applied elastic bandage, *when applied at a time when recumbency and elevation of the limb have reduced the accumulation of capillary and interstitial fluid to a minimum,* will effectively control this sensation of fullness. Of greater importance from the therapeutic standpoint, such mechanical periodic emptying of the sluggish vascular and lymphatic channels contributes materially to an increased, sustained healing rate.

3. As an aid in shrinking the soft tissues of the stump. In the several-week period immediately preceding the final fit of the prosthesis, the soft tissue of the stump should be firm, free from excess adipose tissue, and should present a smooth contour which will adapt well to the socket of the prosthesis. The snug application of the bandage during this period will hasten this process of selective shrinking. The success with which selective shrinking is attained is largely determined by the skill with which the bandage is applied. Not to be overlooked, however, is the necessity for the periodic removal of the bandage during the day to permit re-establishment of circulation through the compressed skin and subcutaneous tissue.

Technique of Bandaging

The physical therapist should become accustomed to but one bandaging technique. Doubtless, there is more than one way in which the bandage may be said to have been correctly applied. However, until the standard practice of

a *b* *c*



d *e* *f*

Fig 499 —Bandaging

a, Start the bandage on the anterior surface of the thigh just below the level of the inguinal ligament, the patient anchoring the end with his thumbs The bandage is then passed over the distal end of the stump posteriorly to the gluteal crease where it is held by the fingers of the patient

b, Two recurrents, *2* and *3*, are passed over the lateral and medial borders of the end of the stump, the ends being secured by the fingers of the patient The beginning of the anchoring turn is shown

c, The bandage ends are anchored by oblique circular turns, beginning at the lateral border of the stump and proceeding around the stump in an oblique fashion The beginning of the hip spica turn is shown

d A hip spica is then applied in an effort to hold the bandage securely as high in the groin as possible From the region of the greater trochanter, as shown in *c*, the bandage is passed obliquely to the iliac crest of the opposite side, posteriorly over the sacrum, and emerges just below the iliac crest of the stump side The patient now turns on his right side and actively extends and adducts the stump during the remainder of the bandage sequence

e, An oblique anchoring turn is then passed around the stump and the spica illustrated in *d* is repeated

f, The bandage is finished by one or more oblique turns about the stump

applying the bandage is shown to be inferior to other techniques, the technique illustrated remains the one which experience has demonstrated to be of value The different aims of bandaging described elsewhere in this section do not necessarily require variations from the standard technique of applying the bandage, the necessary variations relate principally to the tension under which the bandage is applied, together with the frequency and time of bandaging

For the average thigh stump, the technique illustrated in the series of figures comprising Fig 499 is satisfactory Omitted from the illustrations for the sake of clarity are the thumbs and fingers of the patient which are used to secure the end of the bandage and the beginnings of the recurrent folds in Fig 499, *a* and *b*

1 With the patient on his back, the stump held in moderate flexion, and the operator standing on the side of the amputation, facing the stump, the end of the bandage is placed high on the anterior surface of the thigh as illustrated in Fig 499, *a* and secured in this position by the patient's thumbs The bandage is then passed distally over the central portion of the end of the stump and is continued along its posterior surface to the sciatic notch where its edges are caught by the patient's fingers and held at this level

2 The bandage is then folded over the patient's fingers, posteriorly brought over the lateral border of the end of the stump (position 2 in Fig 499, *b*), superiorly to the level of the bandage end and secured by the patient's thumbs A recurrent is then made over the patient's thumbs and is passed distally over the medial border of the end of the stump (position 3 in Fig 499, *b*), obliquely, to the posterolateral border of the stump This, likewise, is secured by the patient's fingers All during this procedure, the patient has maintained control over the end of the bandage and the recurrents so that there has been no relaxation of tension (if tension has been exerted in such application)

3 From the lateral border, as shown in Fig 499, *c*, the bandage is passed over the anterior surface of the thigh to anchor the ends of the bandage From the medial border the bandage is again carried over the posterior surface in a downward and outward direction, emerging laterally distally to the level of the beginning of the anchoring turn

NOTE This principle of applying the circular bandage turns in an oblique fashion, rather than direct circular turns, must never be violated, otherwise a constricting or tourniquet effect on the stump is exerted A too tight anchoring turn at this point can completely defeat the purpose of the bandaging application It is far better to have the patient retain tension on the end and recurrents of the bandage until several oblique anchoring turns have been made than to apply the first anchoring turn so snugly that the patient can release his hold immediately

4 The anchoring turns are completed, as shown in Fig 499, *c*, by passing the bandage over the thigh anteriorly, proceeding medially in an oblique direction, over the posterior surface of the thigh in an upward, outward direction, emerging laterally at the level of the greater trochanter

5 The patient now turns on his side, stump side up, and *while he maintains the stump in a position of extension and adduction*, a spica turn of the bandage is applied around the hip as shown in Fig 499, *d* The bandage is brought from the level of the greater trochanter anteriorly, crossing obliquely to the opposite crest of the ilium, thence posteriorly across the sacral region, emerging laterally just below the iliac crest of the stump side

6 As shown in Fig 499, *c*, the bandage is brought obliquely downward and inward, looped about the thigh, passed over the greater trochanter, and the path

of the previous hip spica is retraced. The patient still remains on his side until the process is completed and the end of the bandage securely anchored by clips.

7. Fig. 499, *f* illustrates the completed bandage.

NOTE. The defects inherent in this method of bandaging are seen even in the diagrams.

a. Guard against employing such a narrow bandage that it curls over the iliac crest in the beltlike fashion. Such a bandage is uncomfortable. An uncomfortable bandage will not be therapeutically successful. The patient will squirm or adjust it until comfort is attained, such adjustments seldom maintain the proper tension of the bandage on the stump.

b. Bandage the thigh as high as possible to avoid a bulging roll of fat and soft tissue which not only may cause the stump to be improperly shaped (see Fig. 500) but also may cause circulatory embarrassment distally.

c. Most important of all, even with the technique of application of the bandage accomplished correctly, it is very easy for the patient to cause the thigh to assume a position of flexion and abduction. Almost invariably after the patient has been in a sitting position, it will be found that the bandage will not maintain the thigh in extension. Keeping the hip spica turns as far posterior to the greater trochanter as possible will minimize this tendency, but no measure will entirely prevent it.

8. The below-knee stump is bandaged in the same fashion as shown in Fig. 499, *a*, *b*, and *c*. If the stump is too short to permit the bandage to be finished with anchoring turns below the level of the patella, an anchoring turn above the knee may be carried out as follows: with the leg in extension and the bandage roll over the head of the fibula, in a position analogous to that shown in Fig. 499, *c* the bandage is carried obliquely upward, anteriorly and medially, superior to the patella, around the lower portion of the thigh, downward and medially, superior to the patella, to the leg where the end is anchored with clips.

NOTE. Avoid placing the anchoring turns so far posteriorly at the knee joint that the leg is held in flexion.

Errors in Bandaging

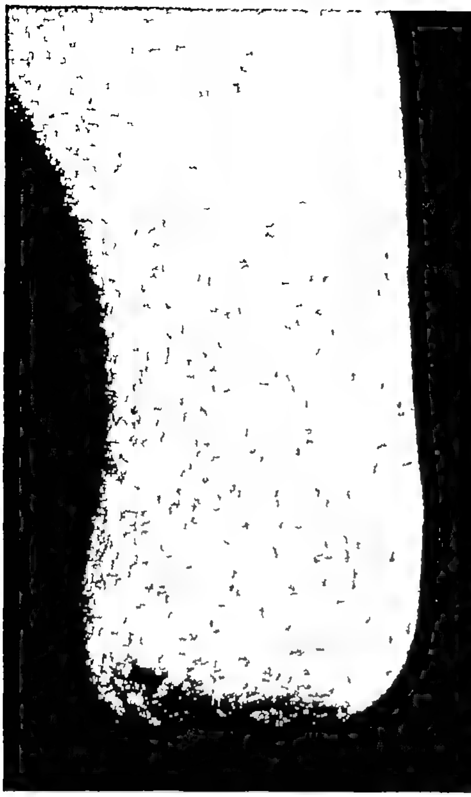
1. Errors in the Technique of Application of the Bandage

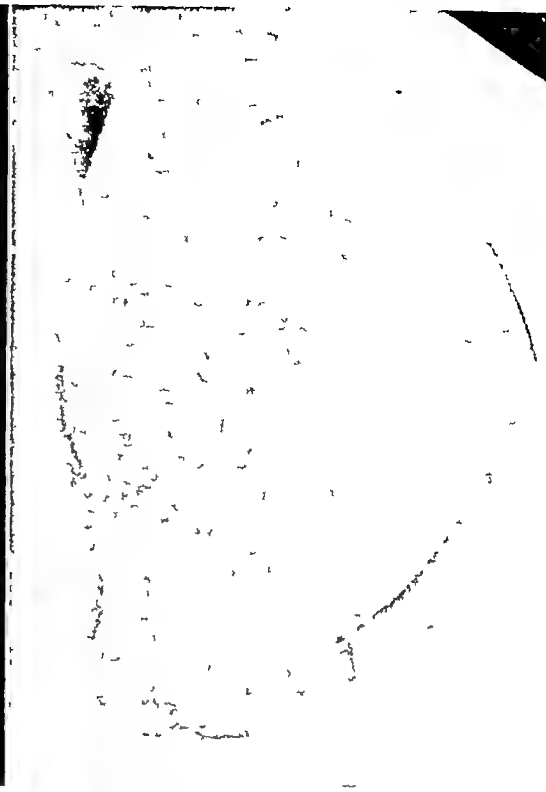
a. When the bandage is applied over the distal surface of the stump, undue tension may be exerted in order to prevent "dog ears" of the projecting edges of the bandage. On removal of the bandage, its edges may be marked on the skin by a reddened line, occasionally dotted with punctate hemorrhages, caused by the salvage, which is firmer and less elastic than is the body of the bandage. The cutaneous area between these marks is edematous.

b. Application of the spirals of the bandage in a circular fashion. This tendency is particularly pronounced toward the proximal portion of the stump. The nearer the proximal portion of the stump, the narrower the spirals tend to become, the more tightly the bandage is applied in order to be anchored firmly, and the greater the constricting or tourniquet effect which results. Bandaging in this fashion will, of course, produce edema of the distal portion of the stump, as shown in Fig. 500. It should always be borne in mind that the spirals must be applied obliquely if this blocking effect on the circulation is to be minimized.

c. Bandaging too low. A bandage which does not influence the entire stump will result in an odd-shaped stump which is difficult to fit with a prosthesis socket. The result of bandaging in this fashion is shown in Fig. 501.

d. Too many bandages. When each bandage is applied correctly additional bandages do not produce undesirable results. However, it is usually impossible

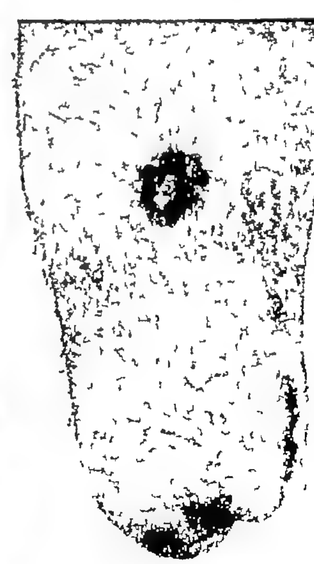




500 501

Fig 500—Improper bandaging A bandage applied too tightly toward the proximal end of the stump will produce edema and soft tissue swelling distally (Walter Reed General Hospital Neg No 4251)

Fig 501—Improper bandaging A bandage applied too tightly toward the distal end of the stump will produce the asymmetric stump illustrated here Note also the dimpled crease where the incision site has become adherent to the subcutaneous tissue (see also Fig 502) (Walter Reed General Hospital Neg No 4254 2)



502 503 504

Fig 502—Improper bandaging Constriction of the distal end of the stump over too long a period of time frequently will produce adherence of the scar to the subcutaneous tissue and bone end (Walter Reed General Hosp Neg No 4179 3)

Fig 503—Improper bandaging Ulceration over the head of the fibula caused by excessive tension by the bandage (Walter Reed General Hosp Neg No 4643 2)

Fig 504—Improper bandaging Ulceration over the tubercle of the tibia caused by excessive tension by the bandage (Walter Reed General Hosp Neg No 4178-2)

to detect errors in the application of the bandage when the stump is thickly padded with them It is very doubtful that additional therapeutic benefit is achieved with multiple bandage layers Three or four bandage layers are adequate for all ordinary purposes

e Overuse of the same bandage As noted previously, the all-cotton bandage can seldom be reapplied to the stump for the reason that stretch robs it of its elasticity and compressibility Since the usefulness of the bandage revolves about its elastic properties, it is difficult to conceive any therapeutic purpose being served by the application of inelastic or stretched bandages

f Inexpert bandaging Too frequently a patient with a thigh stump is instructed to bandage his own stump Unless the physiatrist is completely satisfied with the technique and results of such bandaging, it is usually far more satisfactory for this to be done by one with training and experience in bandaging

2 **Errors in the Therapeutic Prescription of Bandaging.** The gravest errors in bandaging may result from the erroneous concept that each application of the bandage should attempt to shrink the stump, regardless of whether shrinking is indicated Snug application of the bandage before approximately four to six weeks following surgical revision of the stump, or before shrinking is indicated, may result in the occurrence of one or more of the following

a Healing will be delayed as a result of undue superficial soft tissue compression with its attendant defective circulation

b A dimple or crease will form on the distal end of the stump, as illustrated in Fig 502 Through ischemic fibrosis this becomes adherent to the bone end and subcutaneous tissue Clinically there is frequently pain and discomfort at this site when walking with the prosthesis

c An ischemic ulceration of the skin or a traumatic periostitis may develop from undue compression by the bandage, either at chance locations, or certain sites of predilection, such as the head of the fibula (Fig 503) or the crest and tubercle of the tibia (Fig 504)

Comment

A **Support** When the bandage is to be used for support of the soft tissue, do not expect it to accomplish more than this single purpose During this early postsurgical period, the normal circulatory channels have been greatly disorganized, not only as the direct result of the surgical procedure which necessarily entails vascular interruption but also by the reflex vasoneuropathy incident to it If the indication for amputation was for vascular insufficiency, these factors become of critical importance "Support but do not embarrass the circulation" should be the prime thought in the application of the bandage

Since the patient is commonly only semi-ambulatory at this time, the bandage need not be worn during recumbency Active motion of the joints above the amputation site will accomplish much more toward restoration of normal vasomotor control and vascular mechanics than will the bandage, and should be encouraged as vigorously as the condition of the patient permits The more quickly the vascular system can be restored toward normal, the more rapidly healing occurs the less the edema of the soft tissue, and the more quickly is hastened the day when the prosthesis is acquired The single general exception to the removal of the bandage during recumbency is if the absence of the slight bandage tension on the stump causes increased discomfort to the patient Under this circumstance, it is wiser to provide such support in recumbency, but it should be dispensed with as soon as possible

Whenever the patient is ambulatory, the bandage should be applied before he gets out of bed It should be applied under slight tension to the circumference of the stump Tension distally over the recently healed incision should be avoided The duration of each ambulatory period should be governed to some extent by the way the stump feels to the patient If it begins to feel uncomfortable or swollen, the patient should promptly return to recumbency and remove the bandage Either continued ambulation with removal of the bandage or a tighter application of the bandage is contraindicated

B **Shrinking** Bandaging for the purpose of shrinking the soft tissue of the stump is an effective procedure, provided that this goal is bracketed with the reminder that the bandage cannot squeeze fluid or fat cells out of the stump and also that healthy tissue does not swell With this in mind, the role of the bandage in aiding the shrinking process rests on the accomplishment of three things improving the circulation within the stump, prevention of swelling of the soft tissues, and restoration of the normal tensile strength of the connective tissue of the stump The bandage, when applied correctly, can effectively control soft tissue swelling The normal attrition of disuse accounts for the remainder of the shrinking process

It is believed that a fairly rigid procedure should be followed if the maximum shrinking effect of the bandage is to be realized Since the bandage is concerned essentially with the *prevention* of soft tissue swelling, it should be applied following recumbency, at a time when the circulatory demands have been minimal and the maximal vascular and lymphatic drainage has occurred by way of the normal channels It should be applied under moderate tension snugly to the entire stump, guarding particularly against a tourniquet-like action on the proximal portion of the stump It should be left on for two to four hours provided that it does not feel uncomfortably tight to the patient before this time has elapsed It should then be removed for the same reason that a tourniquet is loosened periodically—to aid re-establishment of the circulation While the bandage is removed, the patient should be recumbent To aid the re-establishment and improvement of the circulation further, the stump may be massaged, Buerger's exercises may be performed, or active motion of the joints above the amputation site should be accomplished Following these procedures the stump should again be bandaged with a freshly laundered Ace bandage or one which possesses the necessary elasticity for effective compression The cycle of bandage compression followed by bandage removal should be repeated faithfully three to four times daily if the maximum benefit is to be achieved from this procedure

To recapitulate, the effectiveness of shrinking the stump is an expression of the compression of the soft tissue into a smaller volume without loss of circulatory efficiency Under the conditions described bandaging of the stump will minimize the fluid accumulation in the capillaries, lymphatics, and interstitial spaces The rapid elimination of the stagnant fluid beds in the soft tissue will remove one of the major conditions for the laying down of inelastic fibrous tissue and will permit the soft tissue to resume its normal elastic qualities instead of the rigid hydrodynamics characteristic of diffuse interstitial fibrosis

PREPROSTHETIC TREATMENT

There are many instances wherein surgical judgment dictates an open amputation, with the purpose and hope of revising the stump at a later date when the local tissue immunity, healing ability, and the general condition of the patient are sufficiently good to insure the success of such an elective procedure Physical measures should not be neglected during this interim period Even

though the local condition of the involved extremity may preclude such measures in the individual case, attention should be paid to the uninvolved portions of the body Unless the patient is quite ill, a fairly complete and reasonably accurate estimation of the status of the body mechanics, described under Evaluation of Body Mechanics, can usually be performed Such information provides a guide for such exercises as can be performed at that time, and, equally important, serves to eliminate unneeded exercises often prescribed empirically If the patient is too ill for this procedure, attention to simple bed posture will often serve to prevent the insidious development of muscle imbalances which become obvious during the later, ambulatory period These comments are in no sense to be construed as artificially bolstering physical medicine interest in the patient's case The greater proportion of the stubborn defects in posture and body mechanics arise during this period Any means by which these defects can be minimized or prevented without jeopardizing the patient's progress toward surgical recovery are to be encouraged

Measures Applicable to the Unhealed Stump Itself

a **The Whirlpool** Infected lesions are often remarkably benefited by this procedure Unless the gauze dressings may be removed easily with minimal trauma to the delicate epithelizing perimeter and granulating floor of the lesion, the stump, dressing included, is placed in the bath The dressings are either allowed to float from the surface of the lesion or very gently removed from it under water The mechanical removal of purulent material from the lesion by the whirlpool bath can then be accomplished without harming the healing surface Unless there is evidence that the skin cannot tolerate the water, the stump is immersed in the bath for fifteen minutes at water temperatures not to exceed 105 degrees Fahrenheit This treatment may be repeated as often as twice daily in heavily infected instances and may be continued until several days before surgical revision of the stump It is urged that the bath temperature not exceed 105 degrees, since there is evidence that higher temperatures are injurious to the newly formed epithelium at the margins of the lesion The necessity for gentle removal of the dressings is worth while emphasizing, for it is felt that a measure of harm can result from the hasty, rough jerking of the dressing from the lesion The striking relief from pain in many instances, the rapid conversion of a heavily infected wound to a cleaner, more healthy-appearing one, and the improvement in the circulation of the stump adequately justify this procedure on clinical grounds alone

The chance for further infection of the stump or for cross-infection appears to be only theoretical When the whirlpool bath is drained and the walls scrubbed down with an antiseptic such as 5 per cent cresol, subsequent filling of the tub will demonstrate a bacterial count and flora no different essentially from that of ordinary tap water This precaution of cleansing the tub is simple and does not complicate the treatment program In the experience of the author, many hundreds of open lesions have been treated without evidence of cross-infection Certainly the clinical value of this procedure far outweighs the theoretical possibility of further infecting the stump

b **Zinc Peroxide Ion Transfer** Sluggishly healing indolent-appearing lesions may often be remarkably improved by this procedure In fact of those physical agencies which may be classified as healing adjuncts, in the experience of the author, this procedure is most applicable to unhealed lesions of this type

The technique employed is as follows The lesion is gently cleaned with 50 per cent hydrogen peroxide to remove any necrotic material, pus, and any other extraneous debris After the lesion has been carefully blotted dry with absorbent

cotton, dry activated zinc peroxide powder is blown onto the surface, care being exercised to ensure that crevices are filled with the powder. A square of gauze, wet with warm saline solution, is applied over this region. Over this is then placed the positive electrode, the negative, indifferent electrode is placed over the lumbar region. Three to five milliamperes of constant current are then passed for fifteen to twenty minutes. If the patient complains of sensations of burning or discomfort, in the absence of technical error in the application of the electrode, the current value should be immediately reduced still further. After the electrodes are removed, a dry sterile dressing is placed over the lesion.

The gross appearance of the lesion is many times completely changed by this treatment. A surface which was previously moist and exudative now appears dry. Such inhibition of weeping persists for several hours.

c. **Ultraviolet Irradiation.** This is provided by the conventional air-cooled, hot quartz type of ultraviolet generator. For the purpose of encouraging healing, this procedure is valuable when fractional doses are given. It has been found that ¼ M.E.D. given daily will maintain an accelerated healing rate, larger doses, if repeated frequently, at first stimulate, then appear to retard healing. The same precautions regarding gentle cleansing of the lesion apply here as has been noted previously.

Folliculitis of the stump occasionally becomes a problem sufficiently serious to delay or modify the treatment program. Rarely of serious moment in itself, it constitutes a potential threat to the security of healing by reason of the secondary infection present in the lesions. This condition may be aborted or held in check by the prophylactic use of ultraviolet irradiation to the unscreened skin to the extent of 1 M.E.D. twice weekly. The same procedure may be employed in more widespread involvement of the hair follicles, however, other measures (medicinal, omission of bandaging, and infrared irradiation) may render this procedure one of second choice.

d. **Procaine Ion Transfer.** Not infrequently, unhealed stumps are extremely painful, almost to the point of causalgia. Such pain may exist even in cases which otherwise appear to be healing normally. The use of 1 per cent procaine by ion transfer may alleviate pain which has proved intractable to all other measures but heavy sedation or narcotics. By no means is this measure uniformly successful in permanently relieving the pain, but it may do so in many instances. The procaine solution consists of

Procaine HCl		5 Gm.
Adrenalin (1:10)		2.5 c.c.
Alcohol, 95%	q.s.	500 c.c.

A piece of gauze, larger than the area to be treated, is soaked in the solution and applied soaking wet to the cleansed lesion. This is then covered with the usual warm, saline-soaked electrode and is connected with the positive pole of the source of constant current. Three to five milliamperes of constant current are passed for twenty minutes. The relief from pain which results from this treatment often persists for a matter of hours. Occasionally, patients with extensive lesions complain of increased pain when the alcoholic solution is employed. This complaint can be circumvented by the use of normal saline solution as a solvent rather than the alcohol. The relief from pain with the aqueous solution, however, is not so complete and is of briefer duration.

e. **Penicillin Ion Transfer.** The use of so many medicinal agents by ion transfer naturally led to a trial of the introduction of penicillin locally by this means. The author's experience can be summarized very briefly. Varying

strengths of solutions of calcium penicillin were employed, introducing the penicillin "ion" by negative electrophoresis Little clinical effect was noted except with solutions of which the penicillin strength exceeded 200 Oxford Units per cubic centimeter In brief, this action seemed no greater than that following systemic penicillin therapy or following continuous local applications of penicillin solutions, for this reason the procedure was abandoned

f **Bandaging.** Bandaging in this stage of treatment should be limited to little more than a means for holding an indicated dressing in place Any restriction placed on the superficial circulation will be reflected in delay in healing of the open wound On the other hand, it is quite possible to apply the bandage so that its tension will be so slight as not to embarrass the circulation, yet gentle enough to prevent shifting of the dressing covering the unhealed wound

g **Exercise** The bulk of experience concerning exercise of the involved extremity at this time is that exercise as such should be omitted Active motion of the joints above the amputation site will maintain mobility of the joints and periarticular structures and will provide a mild stimulus to the circulation of that extremity The reasons for such caution concern the impaired circulatory efficiency of the distal portion of the stump together with the high, almost universal incidence of some degree of secondary infection in this region Any procedure which places a further strain on the circulation may result in increased evidence of tissue infection

Measures Applicable to the Rest of the Body

a **Posture** Even though the patient may be confined to bed, attention to simple bed posture will forestall the onset and often imperceptible development of muscle weaknesses and other abnormalities in body mechanics Unless there are sound medical reasons to the contrary, the patient should not be permitted to assume one position habitually Persistent flexion of the knees and thighs particularly should be avoided, especially if the patient is suffering considerable pain, it is the author s conviction that hip flexion contractures develop most rapidly during this period, especially under the immobilizing stimulus of pain The propping up of the head on two or more pillows should be discouraged, since it will lead to weakness of the cervical spine flexors and, through depression of the anterior chest, will interfere with proper breathing and later good posture in the erect position

b. **Breathing Exercises**

1 Costal breathing Simple breathing exercises performed in the supine position without a pillow under the head are of value Chest elevation should be emphasized and, above all, the exercises should be aimed at securing maximum inspiration and expiration Forward flexion of the upper extremities during inspiration, followed by strong adduction of the arms to the side during expiration, can be practiced by the patient many times during the day It is worth while mentioning that the only means of ensuring completeness of expiration is for the patient to make a gentle hissing sound during expiration, when such a sound is inaudible, maximum expiration has been achieved

2 Abdominal breathing With the arms maintained in the inverted-T position and the lower costal margins elevated, the patient should practice abdominal breathing He should during inspiration, relax the anterior abdominal musculature and concentrate on maximum movement of the diaphragms Conversely, during expiration, he should strongly contract the anterior abdominal musculature and maintain such contraction throughout the duration of this portion of the respiratory cycle

c **General Exercises**

1 Pelvic roll, by attempting to approximate the xiphoid and the symphysis pubis, will considerably strengthen the anterior abdominal musculature This is particularly to be desired since straightforward upper and lower abdominal exercises usually cannot be performed at this time

2 The cervical spine flexors and middle and lower trapezius can be exercised in the supine position A small pillow or sandbag is placed between the scapulae With the arms in the inverted-T position, the patient should raise the chest as he strongly depresses the chin and should press the elbows backward as he strongly adducts the scapulae

3 Exercises of the uninvolved extremity should be directed chiefly toward strengthening the quadriceps, the tibialis posticus, and the flexors longus and brevis digitorum

Measures Applicable After the Stump Has Healed

Inasmuch as individual requirements will produce so many deviations from a general program, only the broad treatment aspects will be considered here

a **Bandaging** The technique of bandaging and the aims of bandaging in the early and late postsurgical period were discussed previously in this chapter It is strongly urged that the accomplishments of the compression bandage be carefully separated according to the needs of the patient The procedure of bandaging is too valuable to be wasted on improper technique, tension, or timing of application

b **Exercise** Muscle balance, normal flexibility and extensibility, and absence of contractures are integral prerequisites to later successful walking with the prosthesis Defects in any one of this triad will result in difficulties in using the prosthesis It is obvious that the proper correction of such defects as may exist hinges on the correct diagnosis of their presence Regardless of whether the type of evaluation of body mechanics or the therapeutic exercises previously discussed and outlined in this chapter are followed literally, there must be a consistent system of diagnosis and correction of these defects Although amputation appears superficially as a localized procedure, the physical medicine program must be directed toward the entire individual if its responsibilities are to be properly discharged

TRAINING IN THE USE OF THE PROSTHESIS

Introduction

This phase in the program represents the goal toward which all other aspects of treatment have been directed For the vast majority of patients the acquisition of the prosthesis is the means of linking him once again with his daily activities Surgical skill has been directed toward providing the patient with the amputation stump which will be the most useful to him The physiatrist has been charged with the responsibility of ensuring that the minimum of physical factors exists which will interfere with the proper use of the prosthesis Through the reconditioning program the general muscular tone and development have been heightened The limb fitter has provided the best present-day type of artificial limb which has been properly constructed and fitted for the individual case It would indeed seem an anticlimax to a program in which so much technical skill has been lavished were the patient given the prosthesis and dismissed after a few hurried instructions in its use

Not all individuals experience the same degree of difficulty in learning to walk with the prosthesis The patient with a unilateral below-knee amputation

seldom has difficulty in walking, an intensive program for him is unnecessary This does not relieve the physiatrist, however, of the responsibility of being certain that the patient *does* possess the necessary ability to utilize his prosthesis, if such ability is lacking, he should be as carefully instructed in the proper use of the prosthesis as should the above-knee amputee The individual who slowly learns to walk should not be pushed beyond the limits of his ability to learn It is believed that little really has been accomplished when the patient is permitted to omit certain training features simply because he has difficulty in completing them This does not mean that there should be hidebound insistence on the following of a rigid training program but rather that successful utilization of the prosthesis does not consist only of the things the patient can do most easily

Before considering the sequence of training in the use of the prosthesis, it must again be determined that disturbances of body mechanics do not exist and assurance should be forthcoming from the orthopaedic surgeon that the stump will tolerate weight-bearing and that the fit of the prosthesis is satisfactory

Purpose of Training in the Use of the Prosthesis

Before setting down a proposed training schedule for an amputee to follow, the physiatrist should seriously consider how extensive the program should be yet remain within practical limits Training programs have been seen wherein all possible phases of ambulatory activity are taught, other programs have been simplified to little more than a mimeographed sheet of instructions in how to walk Neither type of program was successful, the one because it attempted too much, the other because nothing actually was taught the patient

It is believed that a program will succeed best when it consists of thorough grounding in the fundamental principles of the use of the prosthesis followed by training in the performance of the commonest features of daily activity This is not to decry the occasional value of teaching acrobatics, adaptive sports, or how to go through an obstacle course, let these achievements be reserved for the exceptional individual or be managed by specialized teaching

Equipment

1 **Parallel bars** These should be of such weight and width that the patient can walk with proper posture yet lightly touch the bars for balance or when necessary, grasp them for support A height of 34 inches and a width of 26 inches will be about right for the adult of average height, provisions should be made for varying these dimensions to meet the need of the individual patient The length should be at least 20 feet for the reason that the individual does not assume the natural walking gait in less than 10 feet when starting from a stationary position

2 **Mirrors** Conventional posture training mirrors are highly desirable in order that the patient see himself as he walks These should be placed so that he can see his posture and gait in both the oncoming and the lateral views

3 **Ramp** This may be of any convenient length that will permit several steps to be taken on it It should have a rise of approximately 18 inches per 10 feet and should have a sturdy railing at both sides, if possible The end may terminate in steps back down to the floor level

4 **Steps** Steps of conventional height should be available with a sturdy railing at one side or both sides It is not believed that a useful purpose is served in having the steps of varying height, the principle of stair climbing is to be taught not how to ascend and descend all possible types of stairs

5 **Walking lines** Wherever forward walking is carried out, there should be two lines painted on the floor each 1 to 2 inches wide and 5 inches apart

1 **Balance** Probably the most important single achievement in prosthesis training is learning body balance with the prosthesis The amputee who does not possess this sense of balance with the prosthesis invariably is a poor walker The ability to discriminate the fine details of body equilibrium, such as exists in the nonamputee, can be acquired only through such intensive practice in balance that the details no longer are conscious acts

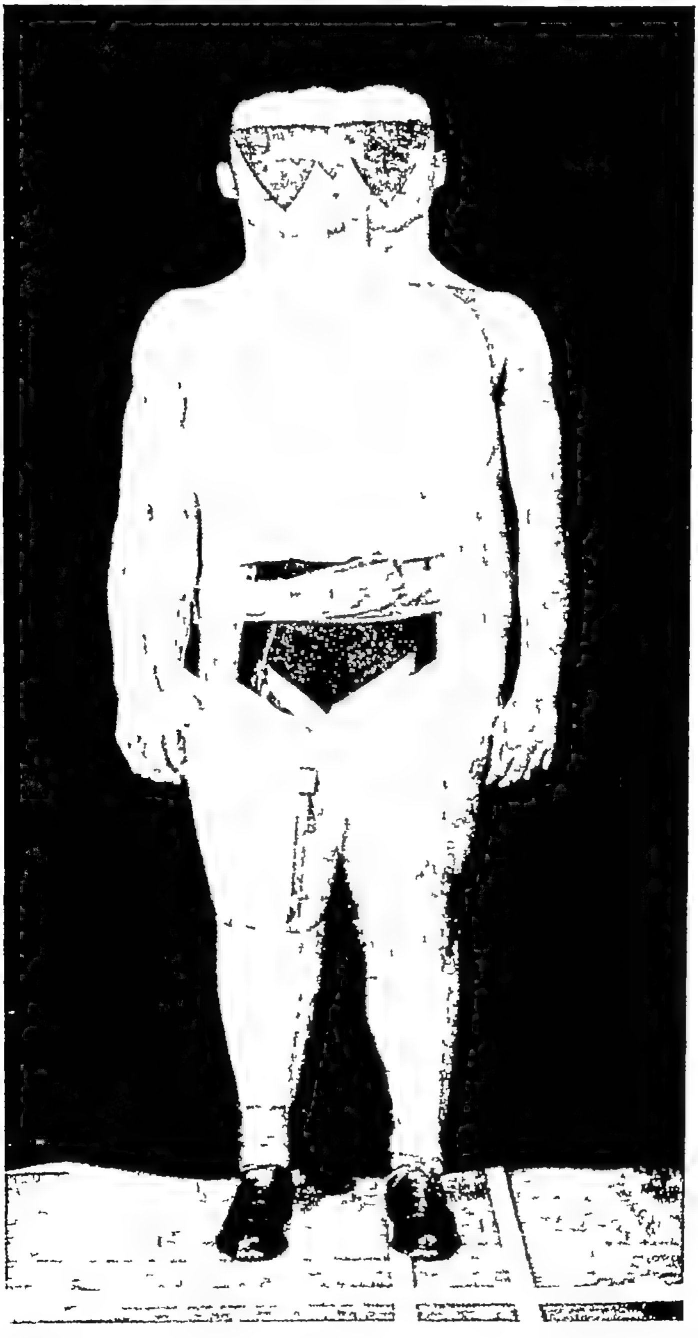


Fig 505—Balance exercise Place feet 8 inches apart and bear weight equally on both feet Correct any postural deviations Concentrate on the "feel" of the prosthesis in this correct standing position The body weight should then be shifted, first to the normal leg, then to the prosthesis, without lifting either foot from the floor Do not look at the feet during this exercise, observation of position in the posture mirrors is permissible (Walter Reed General Hospital Neg No 4542 A24)

a *Initial Exercise* As shown in Fig 505, with the prosthesis correctly applied, the patient stands with his feet approximately 8 inches apart Although he may use crutches or the parallel bars to insure support, he should stand with correct posture, bearing the body weight equally on both lower extremities During this time he should concentrate on the postural sensations from the stump, keeping in mind that this is now the way the extremity feels when his body's weight is well balanced Because of tenderness of the skin of the stump and lack of confidence in the prosthesis, the individual's tendency is to bear the major portion of body weight on the uninvolved extremity Such a tendency should be discouraged, the emphasis being placed on symmetrical weight distribution The universal fear of the prosthesis knee buckling will quickly vanish if the patient remembers that this cannot occur during weight-bearing so long as the greater trochanter of the hip lies in a plane anterior to the rotation axis of the knee joint

When the patient has acquired the "feel" of the prosthesis, the body weight should be shifted and borne completely, first on the normal leg, then on the prosthesis, as shown in Fig 505 During this exercise the feet should remain in contact with the floor This, as well as the other balancing exercises, should be performed before the posture mirrors so that it will be unnecessary to look down to the feet The patient must learn to know the position of the prosthesis by its feel, not by the way it looks Despite the simplicity of this exercise it should be repeated so thoroughly that the habit pattern of prosthesis sense will already have become established before the more advanced features of walking technique are taken up

b *Progression Exercise* Having established the normal sense of standing balance on both lower extremities, balance in forward progression should then be practiced With the prosthesis approximately half the normal length of a step ahead of the body, take a full step forward with the normal leg Without moving the prosthesis, take a full step backward with the normal leg During this time, the patient should concentrate on the feel of the prosthesis as the body weight is briefly borne on it The physical therapist should ensure proper posture in the patient during this exercise, should guard against lateral hip motion of the stump side, and should impress on the patient the necessity for moving forward and backward along an imaginary line perpendicular to the midline of the body This exercise should be repeated at least ten times daily

2 **Straight-Line Walking**· The nonamputee, it may be observed, walks a straight line in forward progression, the inner borders of the heels touching such an imaginary straight line Except in the bilateral above-knee amputee, not only is it possible to duplicate this but doing so will contribute materially to smoothness of walking The bilateral amputee usually must walk with an intermalleolar distance greater than the normal amount in order to maintain satisfactory balance in walking

Inasmuch as a sense of prosthesis insecurity tends to develop when the patient attempts to walk a single straight line, the same principle can be achieved by having him practice walking within the 5 inch space separating the walking lines shown in Fig 505 Later, when walking proficiency has been established, he should practice walking a single straight line, contacting the line with the heels in the same fashion as would the nonamputee

Straight-line walking should not be confused with the position to be assumed in standing If the amputee attempts to stand with the feet this closely together, it not only will be uncomfortable to maintain such position but will be insecure so far as balance is concerned For standing, the feet may be a comfortable distance apart, as shown in Fig 505

3 **Normal Walking Rhythm** Walking rhythm in the nonamputee is composed essentially of equal length steps taken at a certain speed (approximately 60 steps per minute) The same goal can be achieved by the amputee To begin with, emphasis should be directed primarily toward the attaining of normal walking speed, walking form can be coped with later The purpose of this sequence is to establish the mechanics of gait It has been found through experience that the amputee who takes each step slowly and deliberately takes much longer to acquire skillful control of the prosthesis than does the individual who learns to walk at a normal speed The increased facility in the latter person is due in large measure to the fact that gait progression occurs so rapidly that the separate details have dropped down to the level of unconsciously performed acts in general, walking is normally performed in this fashion

Once normal walking speed has been attained, strict attention should be given to insistence on equal length steps Common observation is that the gait of the average unilateral above-knee amputee consists of a short step with the normal leg followed by a long step with the prosthesis Such a gait is often accepted as the necessary accompaniment of the disability That it is due to habit and not the disability is shown by the fact that it need never develop if attention is given to its early correction and by its disappearance with practice in correct walking Perhaps this is a minor triumph, but the elimination of the "amputee gait" is a source of satisfaction both to the patient and to his instructor

Basic Walking Achievements

As stated previously, it is not the purpose of this section to provide a guide for more than the commonplace walking achievements It is believed that the amputee who is thoroughly grounded in these fundamentals will of his own volition attempt the more skillful tasks The performance of the more difficult feats becomes more and more of an individual problem, the solution of which each amputee finds for himself In contrast, the simpler aspects of ambulation are fairly standard, although each amputee may ultimately utilize individual methods for accomplishing a given function

Never during the course of training in the use of the prosthesis should the individual be permitted to forget the three fundamentals of walking balance, straight-line walking, and normal walking rhythm Exercises incorporating these fundamentals should be practiced daily The increased confidence in the prosthesis and skill in its use by the constant repetition of these principles will go far toward making the prosthesis the satisfactory replacement for the amputated extremity

The amount of training necessary for skillful use of the prosthesis depends somewhat on the level of the amputation Unilateral below-knee amputees seldom require extensive training Bilateral below-knee amputees should, in general, receive the same type of training as the unilateral above-knee amputee The unilateral above-knee amputee is the commonest of the amputees with which this phase of physical medicine is concerned and the majority of the following comments apply to this type of amputation Bilateral above-knee amputees constitute a group requiring special attention to balance, since there is no normal leg on which to depend for support

1 **Forward Walking** This should be practiced between parallel bars, walking with the feet between the walking lines

a THE BELOW-KNEE AMPUTEE

(1) *Unilateral* The patient with a unilateral amputation may advance forward with either the normal or prosthesis leg Usually the initial step is taken with the normal leg

(2) *Bilateral* The bilateral amputee usually has one leg which seems stronger and more stable to him than the other The initial step should be taken with this leg

b The Above-Knee Amputee

(1) *Unilateral* The initial step is taken with the normal foot The stump is flexed *quickly* (but not forcibly nor in a jerky fashion) to buckle the knee of the prosthesis and carry the leg forward As the foot of the prosthesis swings past the mid-lateral line of the body, the stump should be *quickly* extended so that the knee of the prosthesis will be locked in extension as the weight of the body is borne on it The patient must practice the timing of the extension of the stump so that the step with the prosthesis leg will equal that of the other Not only is such timing important so that overswing of the prosthesis and "digging in" of the heel is avoided, but it is of equal importance that the prosthesis foot is carried forward smoothly without dragging and that the prosthesis knee is stabilized in extension when the weight is shifted to it

The patient should not be permitted to walk with the prosthesis leg maintained in extension Such a stiff-legged gait not only is a conspicuous and inefficient one, but it invariably will lead to other poor walking habits an abduction-circumduction of the prosthesis in walking, a list of the body toward the normal side, and hiking of the shoulder of the involved side Further, this asymmetric, graceless gait is no guarantee that the knee of the prosthesis will not buckle anyway

The sequence of normal leg, prosthesis leg, normal leg, should be practiced at normal walking speed During flexion, extension, and weight-bearing the patient should concentrate on sensations arising from the stump so that the "feel" of the prosthesis during walking and proper weight-bearing will quickly be acquired

(2) *Bilateral* It is much more satisfactory for the bilateral amputee to practice walking between parallel bars than with crutches Crutch walking itself is a problem of some magnitude in these individuals and should be reserved for use later when gait progression is better established It usually is immaterial whether the initial step is taken with one prosthesis or the other If the patient feels that one thigh is stronger than the other, the initial step should be taken with the stronger leg To take the initial step, shift the weight to the right leg and the left upper extremity, flex the left thigh and move forward, sliding the right hand along the parallel bar as this is done As the left heel touches the floor, the left thigh is *quickly* extended as the body weight is then shifted to the left prosthesis and right upper extremity The right prosthesis and left hand are advanced as the sequence is repeated

To begin with, the forward steps may be very short so that the patient will feel that he is never very far off balance The steps may also be taken very slowly so that he will feel a minimum of insecurity as he progresses one step after the other However, this exercise should be practiced so thoroughly that the fears of insecurity or falling will vanish in the confidence of the stability of the prosthesis, and steps of normal or near-normal length and speed should be achieved as soon as possible

As proficiency in walking increases the patient should then practice using two crutches, or preferably two canes, for support in lieu of the parallel bars Guard against the tendency to walk with the canes or crutches forward or ahead of the body Confidence in the stability of equilibrium must reside in the prosthesis, not the canes

2 **Turns.**

a THE BELOW-KNEE AMPUTEE

(1) *Unilateral* Turns are usually accomplished without difficulty, pivoting on either foot To begin with, however, it is usually better to shift the body weight to the ball of the normal foot and pivot toward the prosthesis side While the body weight is borne on the normal leg, as in forward walking, the prosthesis may then be securely placed in the new position and gait progresses in this direction

(2) *Bilateral* Turns are taken on the balls of both prosthesis feet If a right turn is to be made, place the left foot slightly forward and turn to the right, the body weight is then transferred to the right foot and gait progression occurs in the new direction

b THE ABOVE-KNEE AMPUTEE

(1) *Unilateral* The body weight is borne on the normal leg as the patient pivots on the balls of both feet, turning toward the side of the prosthesis As skill develops, he should learn to turn to either side

(2) *Bilateral* Pivots are usually too difficult to perform to utilize in making turns Awkward as it may seem, turns are best accomplished by walking in as small a circle as possible

3 **Sitting**

a THE BELOW-KNEE AMPUTEE

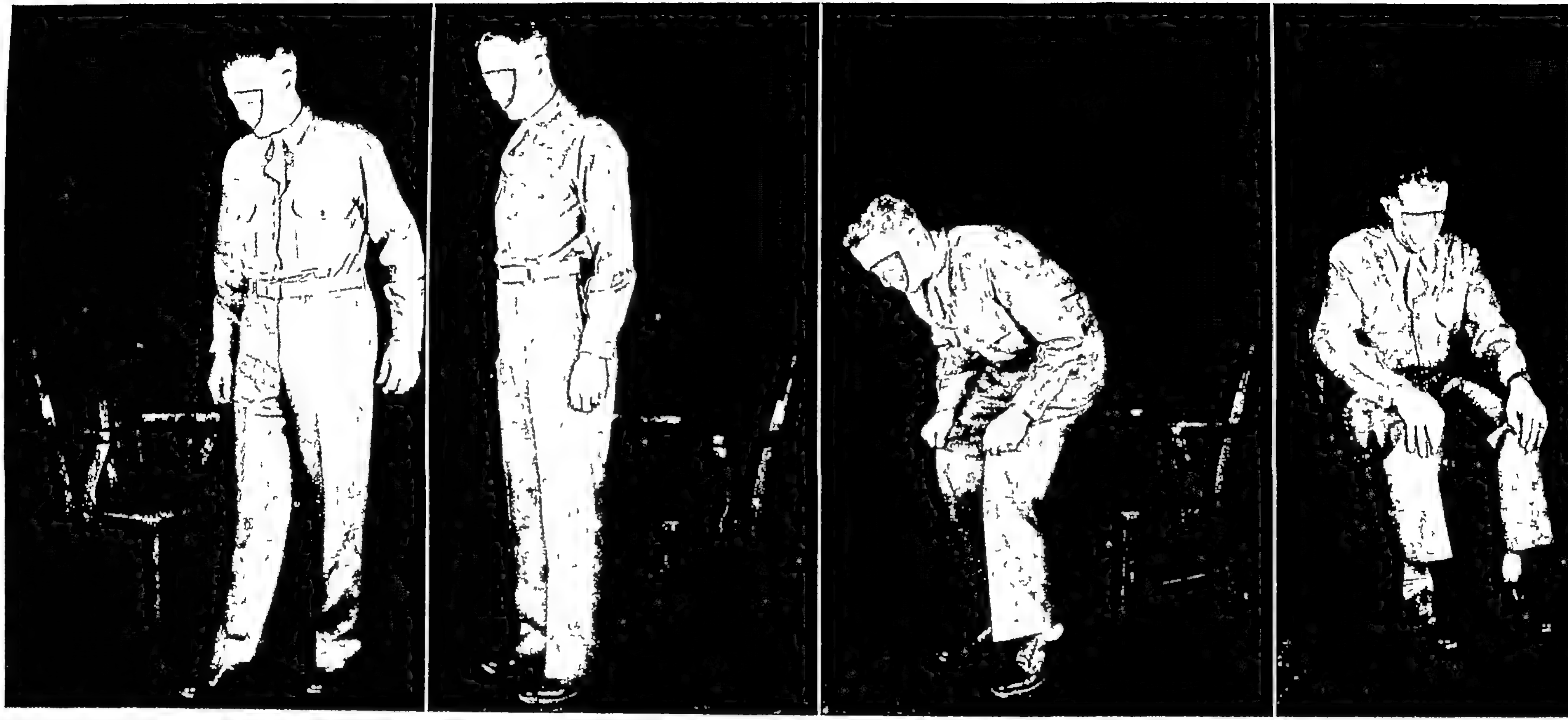
(1) *Unilateral* This individual approaches a chair and sits as he would normally, the prosthesis usually posing no problem

(2) *Bilateral* See b(1) below

b THE ABOVE-KNEE AMPUTEE

(1) *Unilateral* The series of figures comprising Fig 506 illustrate the details of sitting Fig 506, *A* shows the individual approaching the chair from the side, pausing with the right (normal) foot at the right front leg of the chair While the weight is borne on the right (normal) leg, a 90 degree turn to the left is made on the balls of both feet and the prosthesis is brought backward in line with the opposite leg as shown in Fig 506, *B* While bearing the body weight on the right leg and grasping the trousers for balance if necessary, as shown in Fig 506, *C*, or placing the hands on the knees the individual bends forward and lowers himself into the chair After sitting, the patient flexes the thigh of the prosthesis slightly and presses the leg to 90 degrees flexion to align it with the normal leg as shown in Fig 506, *D* If it is desired to sit with the legs crossed, place the normal leg over the prosthesis in order that this movement be accomplished easily without an awkward shifting of feet

(2) *Bilateral* For the bilateral amputee to sit, the chair must either be held by an assistant or be so heavy that it will not move The floor must not be slick nor should he stand on a rug that may slip under him The series of pictures shown in Fig 509 are helpful in following the sequence The patient approaches the chair and leans forward, bearing part of the body weight on the two hands as shown in Fig 509, *C* While maintaining the left leg in extension, the body weight is borne on it and the two hands, as the right thigh is flexed and the foot brought beside the right front chair leg as shown in Fig 509, *B* The patient then turns to the left and eases himself into the chair as shown in Fig 509, *A*, control of this movement being maintained by the weight distribution on the two hands and the extended prosthesis



A B C D

Fig 506—Sitting Unilateral Amputee

A, Approach the chair from the side Pause with the right (normal) foot at the right front leg of the chair Bear the majority of the body weight on the right foot

B While bearing the body weight on the right foot, pivot 90 degrees to the left on the balls of the feet

C, Bend forward at the waist Grasp the trouser creases or place the hands on the knees for stability Lower self into the chair, still bearing the body weight on the right (normal) foot

D, Align the prosthesis with the normal foot by lifting the prosthesis slightly and pressing backward on the leg with the hand (Walter Reed General Hospital Neg No 1010 A33, A22, A34, A28)

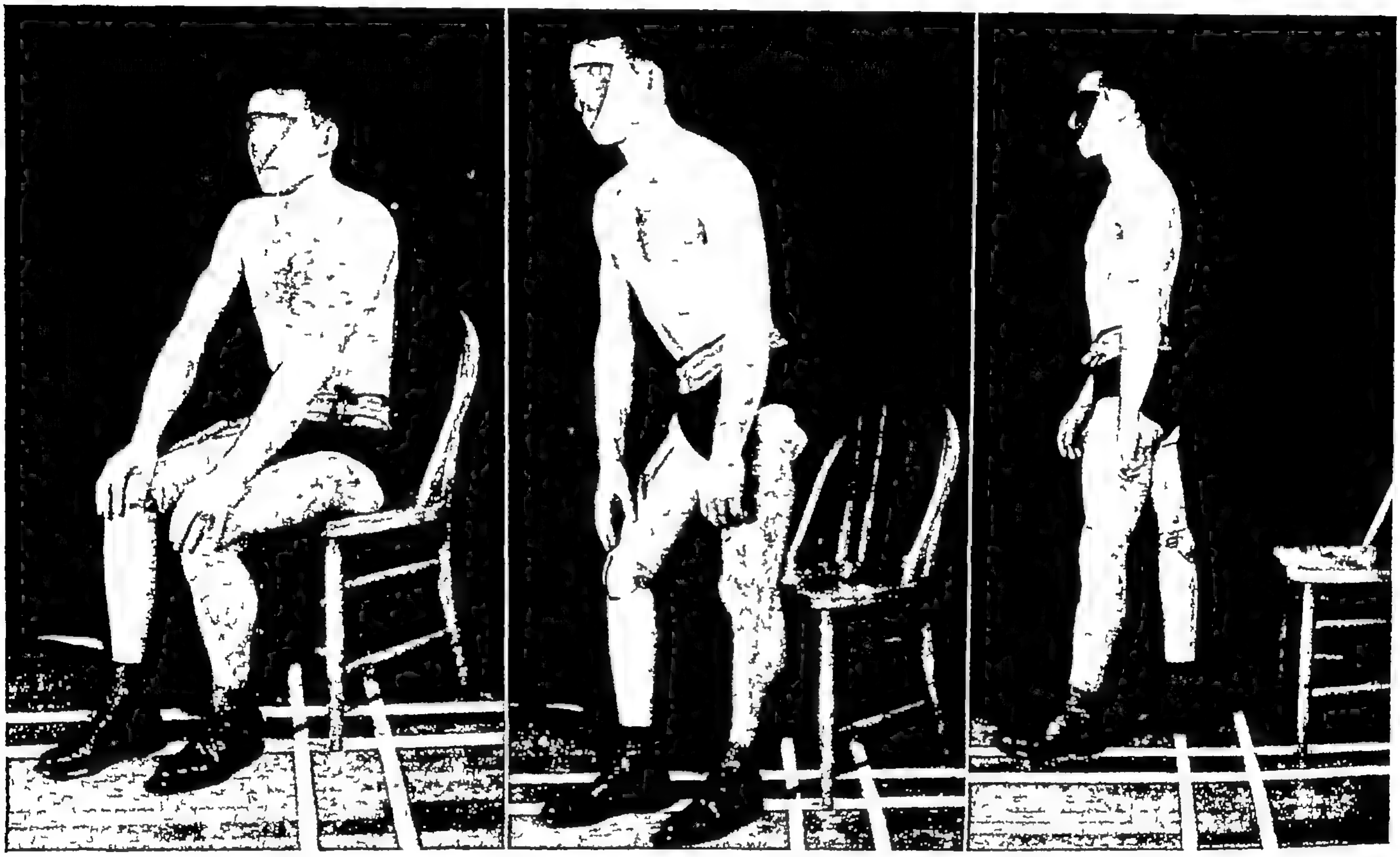
4 Rising

a The Below-Knee Amputee

Both the unilateral and bilateral amputee will employ the technique illustrated in Fig 507

b The Above-Knee Amputee

(1) *Unilateral* The normal leg is placed posterior to the alignment of the prosthesis foot and the hands rest on either knee as shown in Fig 507, *A* The individual leans forward, and as he does so he pushes off strongly with both hands, and rises, bearing the body weight on the normal leg as shown in Fig 507, *B* Having attained the erect posture, he is in position to extend the prosthesis knee, shift the body weight to the prosthesis, and step forward with the normal leg as shown in Fig 507, *C* An alternative method of rising, pushing off from the chair rather than the knee, is shown in Fig 508



A *B* *C*

Fig 507—Rising Unilateral Amputee

A, Place the normal foot to the rear, lean forward, and place both hands on knees

B, Push up strongly at the end of the forward lean and rise, bearing the body weight on the left (normal leg)

C, Step forward with the normal leg

(Walter Reed General Hospital Neg No 4542 A28, A20, A25)

Fig 508—Rising Unilateral amputee (alternative method)

A, Place the normal (right) foot to the rear, lean forward, and place hands on arms or sides of chair

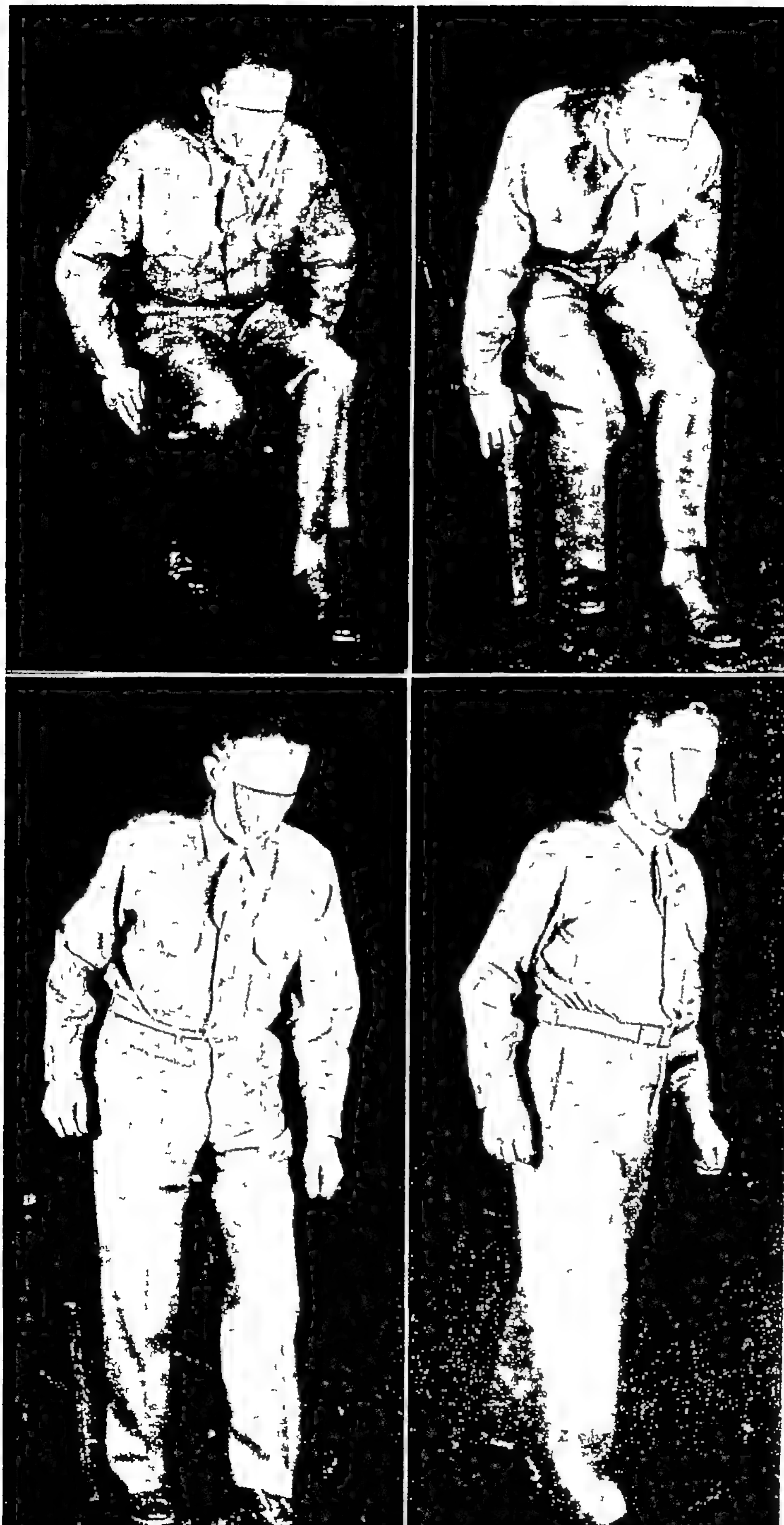
B, Push upward strongly with the hands, bearing the body weight on the normal (right) foot

C, Shift the body weight to the prosthesis

D, Step forward with the normal (right) foot

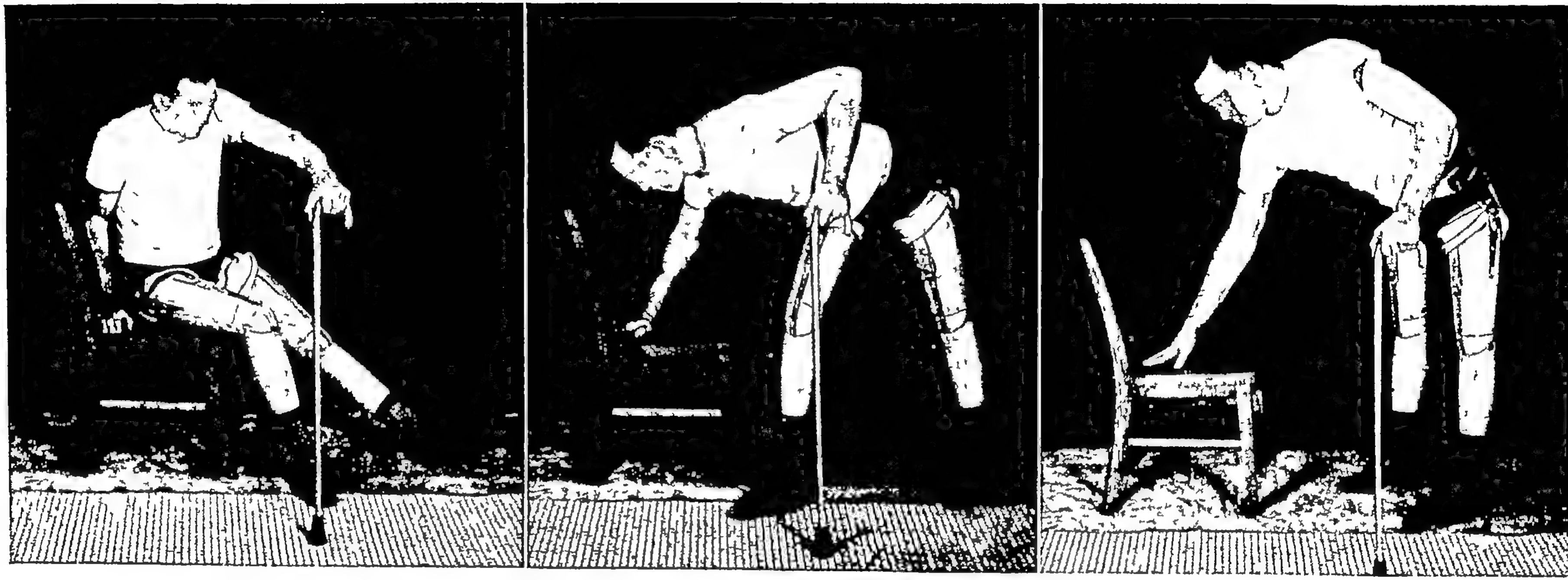
(Walter Reed General Hospital, Neg No 4010 A36, A37, A25, A24)

A B



C D

Fig 508 *(For legend see opposite page)*



A B C

Fig 509 —Rising Bilateral amputee

A, Half pivot to the right Extend the left prosthesis leg Place the cane (or crutch) opposite the right, flexed leg Place the right hand firmly on the chair set

B, With a strong upward thrust from the right upper extremity, as pivoting continues, the position shown is attained, stability being maintained by the upper extremities and the left lower extremity The right knee is immediately extended to ensure greater stability of equilibrium

C, By pushing upward gradually with the upper extremities the erect posture is gained

This series in reverse demonstrates the sequence of actions which the bilateral above knee amputee follows in sitting

C, Bend forward at the waist, place one hand on the seat of chair, cane or crutch at side

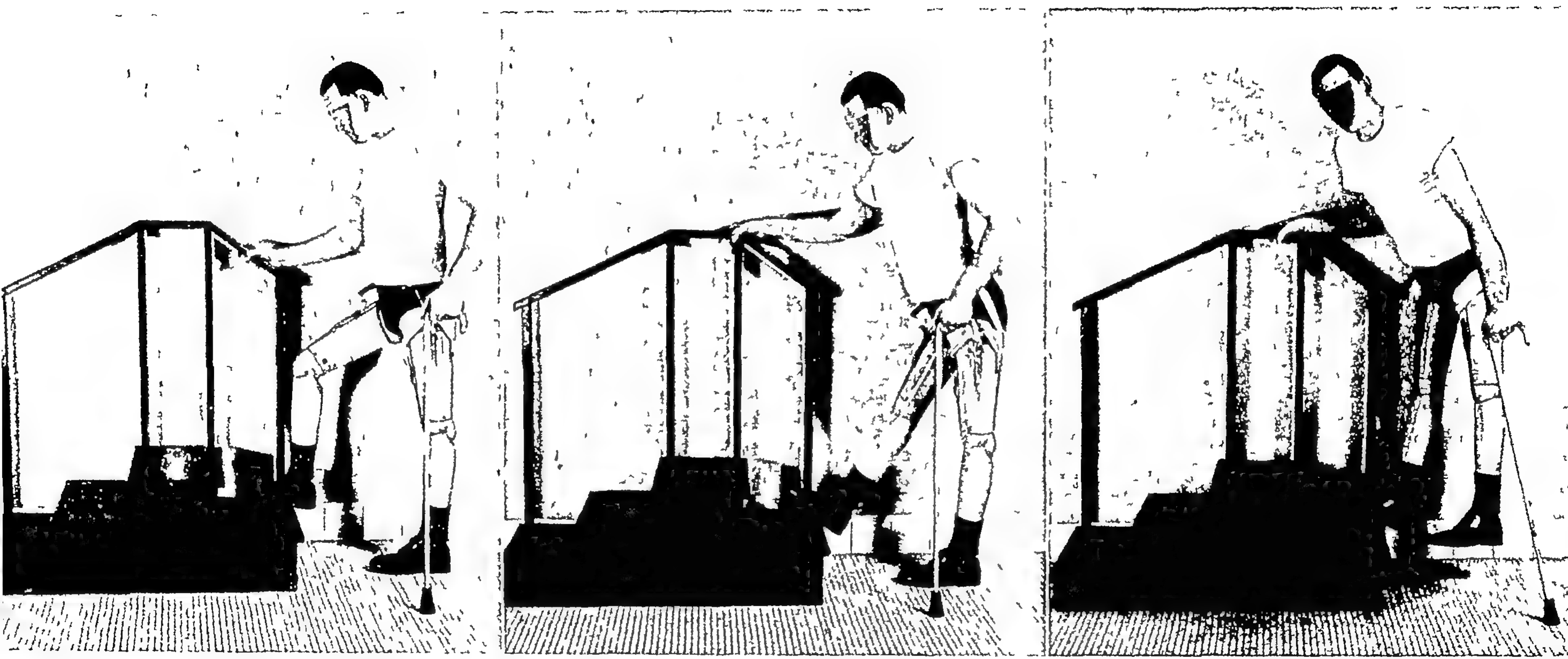
B, Bear body weight on right hand Flex right knee Stability is maintained by extended left lower extremity and the cane

A, Pivot to the left and ease the body weight into the chair, guiding the motion chiefly with the right upper extremity

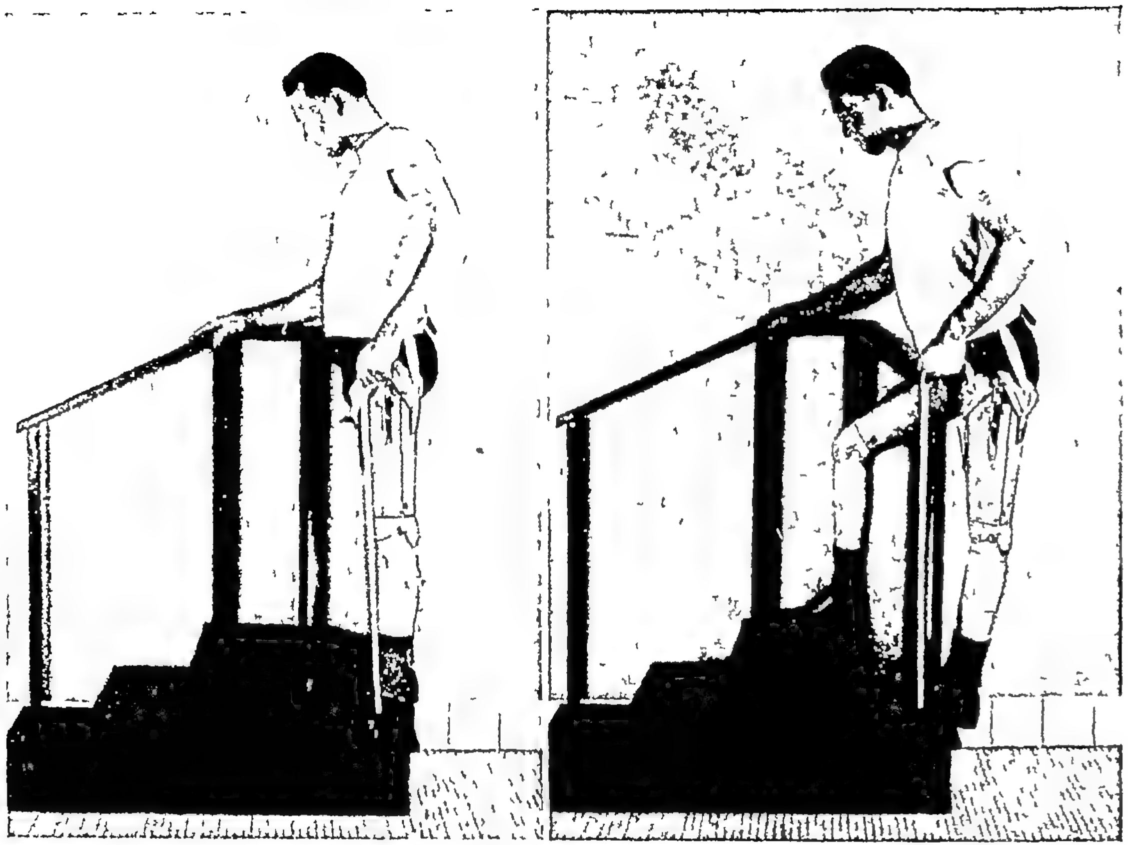
(Walter Reed General Hospital Neg No 4746 A8, A3, A10)

A *B* *C* *D*

Fig 510—Ascending stairs Unilateral Amputee
A, Turn approximately 45 degrees toward the prosthesis (left) side Shift weight to the extended prosthesis and step up with the normal foot
B, As above, except that, for speed, the normal foot may step up two steps
C, Lean forward, bear the body weight on the right leg, and raise the extended prosthesis to this higher level
D, Place the prosthesis beside the normal foot Repeat the sequence for each succeeding step
(Walter Reed General Hospital Neg No 4010 A58, A59, A61, A41)



A B C



D *E*

Fig 511 —Ascending stairs Bilateral amputee

A, Shift the body weight to the left leg Flex the right knee and thigh, placing the instep of that foot on the tread of the next higher step Grasp the railing firmly with the one hand, the cane firmly with the other

B, Extend the right leg and shift the body weight to it Begin to pull upward on the railing and push up with the cane

C, Push upward with the cane and pull self up to the next higher step, turning the body slightly to the left as this is done in order to provide clearance for the left foot in step *D*

D, Place the left foot beside the right Place the cane beside the left foot Shift the body weight to the left leg Shift the position of the right hand on the railing

E, Repeat step *A* for the next higher step

(Walter Reed General Hospital Neg No 4746 A16, A17, A18, A20, A19)

(2) *Bilateral* The same precautions regarding stability of the footing and the chair pertain here as were noted under *Sitting* The patient turns slightly toward the right side, extending the opposite prosthesis leg and placing the cane well to the side of the flexed foot as shown in Fig 509, A With a strong motion pivoting toward the right side, the patient pushes up from the chair, bearing the body weight first on the right arm and left leg and then also the left arm as the erect position is assumed, as shown in Fig 509, *B* and *C* It must be emphasized that the strong thrust upward and away from the chair must be sufficient to carry the patient to the position shown in Fig 509, *C*, otherwise his balance will not be sufficient to prevent his falling back down into the chair again

5 **Ascending Stairs** Stairs of standard or average dimensions of the riser and tread which have a sturdy railing on both sides for support should be employed

a The Below-Knee Amputee

(1) *Unilateral* This individual should ascend stairs in a manner no different from the nonamputee

(2) *Bilateral* The same technique will be employed as for the unilateral above-knee amputee

b The Above-Knee Amputee

(1) *Unilateral* Steps may be ascended one or two at a time It is better to learn this technique one step at a time, employing the two-step ascent when speed is desired The patient turns approximately 45 degrees toward the prosthesis side, shifts the body weight to the prosthesis and places the normal foot on the next higher step as shown in Fig 510, *A* If two steps are to be ascended at a time, the normal foot is placed on the second higher step as shown in Fig 510, *B*, other details remaining as noted for Fig 510, *A* The patient leans forward slightly, and, bearing the weight on the normal leg, raises himself to the higher level, the prosthesis meanwhile is maintained in extension as shown in Fig 510, *C* Once the prosthesis foot has attained the same level as the normal foot, it is then placed beside the normal foot as shown in Fig 510, *D*, the slight turn of the body toward the prosthesis side permits the prosthesis foot to clear the edge of the step without catching the toe as otherwise would occur in the absence of any such lateral torsion of the body The sequence is repeated for additional steps

(2) *Bilateral* The series of pictures illustrated in Fig 511 apply to the more advanced stage of walking The beginner should employ steps with a sturdy railing on both sides, of the type shown in Fig 510 The sequence of ascent, however, remains the same whichever technique is employed On the assumption that the right thigh is the stronger, the stair railing is grasped firmly with the right hand and the right thigh is flexed, placing the instep of the prosthesis foot on the step as shown in Fig 511, *A* The patient leans forward extending the right prosthesis knee as shown in Fig 511, *B* By pushing off with the cane and pulling with the right arm, the patient shifts the body weight to the right prosthesis and pulls himself up to this step level as shown in Fig 511, *C* By slightly turning the body to the left, meanwhile maintaining firm grasp of the railing, the left prosthesis foot is placed on the step beside the right as shown in Fig 511, *D* The body weight is shifted to the left prosthesis, maintaining stability of equilibrium with the railing and cane, the right thigh is flexed and that prosthesis is placed on the next higher step as shown in Fig 511, *E*, ready for the next step in ascent

6 **Descending Stairs**

a THE BELOW-KNEE AMPUTEE

(1) *Unilateral* There should be no difficulty in descending steps in the same fashion as does the nonamputee

(2) *Bilateral* Until the patient becomes proficient in descending stairs it is better for him to learn and practice descent one step at a time One prosthesis foot is placed on the tread of the next lower step The body weight is then shifted to that prosthesis as the other foot is brought down beside it The railing should be used for support in the early learning phase, but should not be utilized later as balance improves

b THE ABOVE-KNEE AMPUTEE

(1) *Unilateral* The unilateral amputee will learn to descend steps quickly and easily The beginner should practice the following technique on the last

A *B*

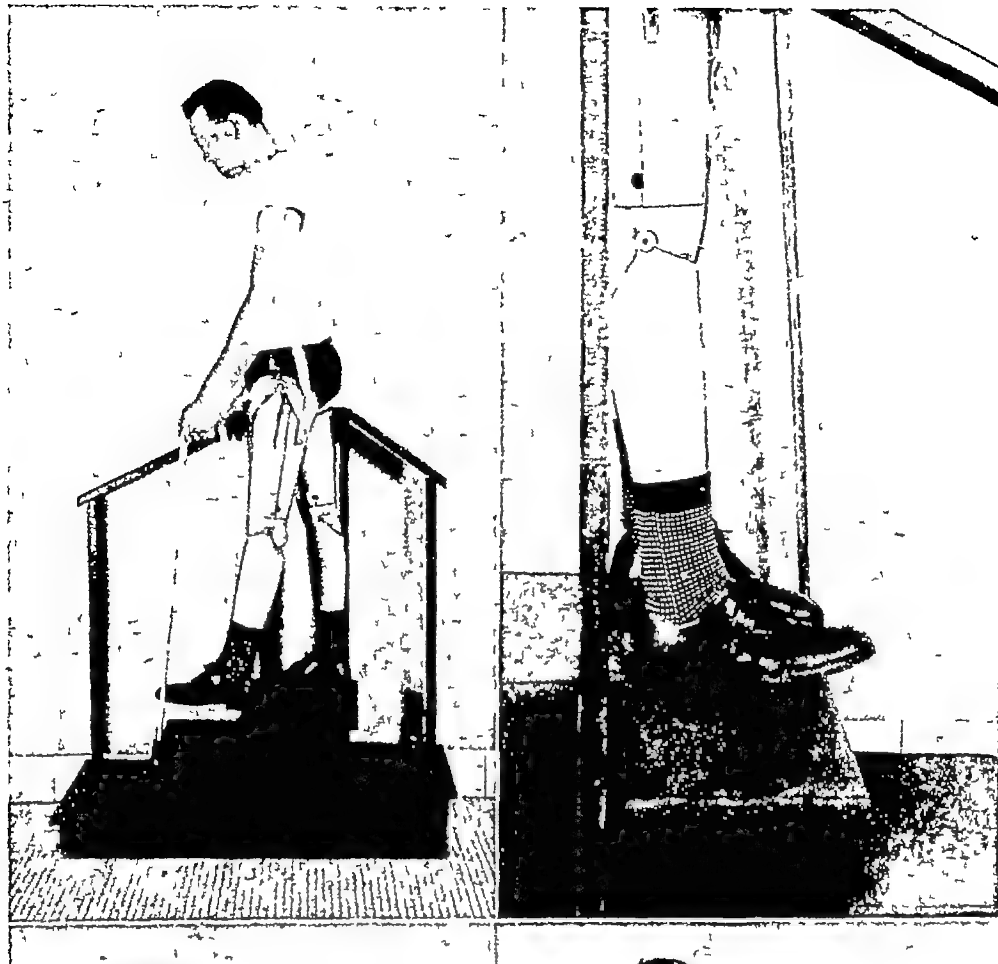
Fig 512—Descending stairs Unilateral amputee

A, Shift the body weight to the right (normal) side Flex the right knee Place the prosthesis on the next lower step, the posterior two thirds of the heel only in contact with the step

B, Shift the body weight to the left (prosthesis) side As this is done, the prosthesis knee automatically will buckle As the prosthesis knee flexes, the normal extremity is placed on the next lower step It is important that the forward edge of the prosthesis heel clears the edge of the step, otherwise, it will catch on the step during this sequence and cause the individual to trip

(Walter Reed General Hospital Neg No 4010 A50, A51)

A *B*



C *D*

Fig 513 *(For legend see opposite page.)*

A *B*

Fig 514 —Stooping Unilateral, below knee amputee

A, The prosthesis is advanced slightly ahead of the normal foot Body weight is borne largely on the normal foot

B, Bend from the waist, bearing the body weight on the normal foot, flex the thighs and legs, and grasp the object

(Walter Reed General Hospital Neg No 4010 A21, A20)

Fig 513 —Descending stairs Bilateral amputee

A, Grasp the railing firmly slightly ahead of the anterior body line Place the cane on the next lower step Place the extended left lower extremity forward with the posterior half of the heel only in contact with the step

B, Bring the right foot forward, placing the heel in contact with the riser of the next lower step This is necessary to ensure extension and stability of the right leg in the subsequent step

C, Carry the body weight forward The left knee will automatically flex The sudden drop of the right lower extremity to the next lower step is broken by bearing part of the body weight on the hands

D, The sequence beginning with A is repeated for each succeeding lower step

(Walter Reed General Hospital Neg No 4746 A2, A23, A1, A11)

two steps of the stairs so that confidence in his ability will rapidly be established and the fear of falling down the steps quickly vanish as proficiency develops For establishing confidence in this procedure the railing may be grasped for support, but, as quickly as possible, the use of this support should be discontinued and descent practiced in the following manner While the body weight is borne on the normal (right) leg, the prosthesis *heel* (with the leading edge of the heel extending over the edge of the step) is placed on the step below as shown in Fig 512, *A* The body weight is shifted to the prosthesis and the normal foot is brought down to the next lower step as shown in Fig 512, *B* The patient should understand that the prosthesis knee will automatically flex as the normal foot descends, the apparent momentary insecurity is of no concern since the body weight is immediately assumed by the normal foot as it strikes the lower step The prosthesis heel is placed on the succeeding lower step as in Fig 512, *A*, and the sequence is repeated

(2) *Bilateral* For purposes of illustration, the single rail and cane technique is shown in Fig 513 The beginner should employ two rails until the mechanics of descent have been mastered The body weight is shifted to the right prosthesis as the left foot is advanced until only the posterior half of the heel is on the step as shown in Fig 513, *A*, equilibrium is maintained by the rail and cane The body weight is then shifted to the left prosthesis as the right prosthesis is advanced and the foot slid down the riser of the next lower step as shown in Fig 513, *B* While maintaining the right leg in extension the body weight is carried forward, the knee of the prosthesis will automatically flex as the weight-bearing line of the body passes anterior to the hip joint, and the body weight will be transferred to the extended right leg as shown in Fig 513, *C* While maintaining the body weight on the right prosthesis, the left heel is placed on the edge of the step as in Fig 513, *D* and the sequence of Fig 513, *A* through Fig 513, *C* may be repeated

7 Stooping for Objects

a THE BELOW-KNEE AMPUTEE

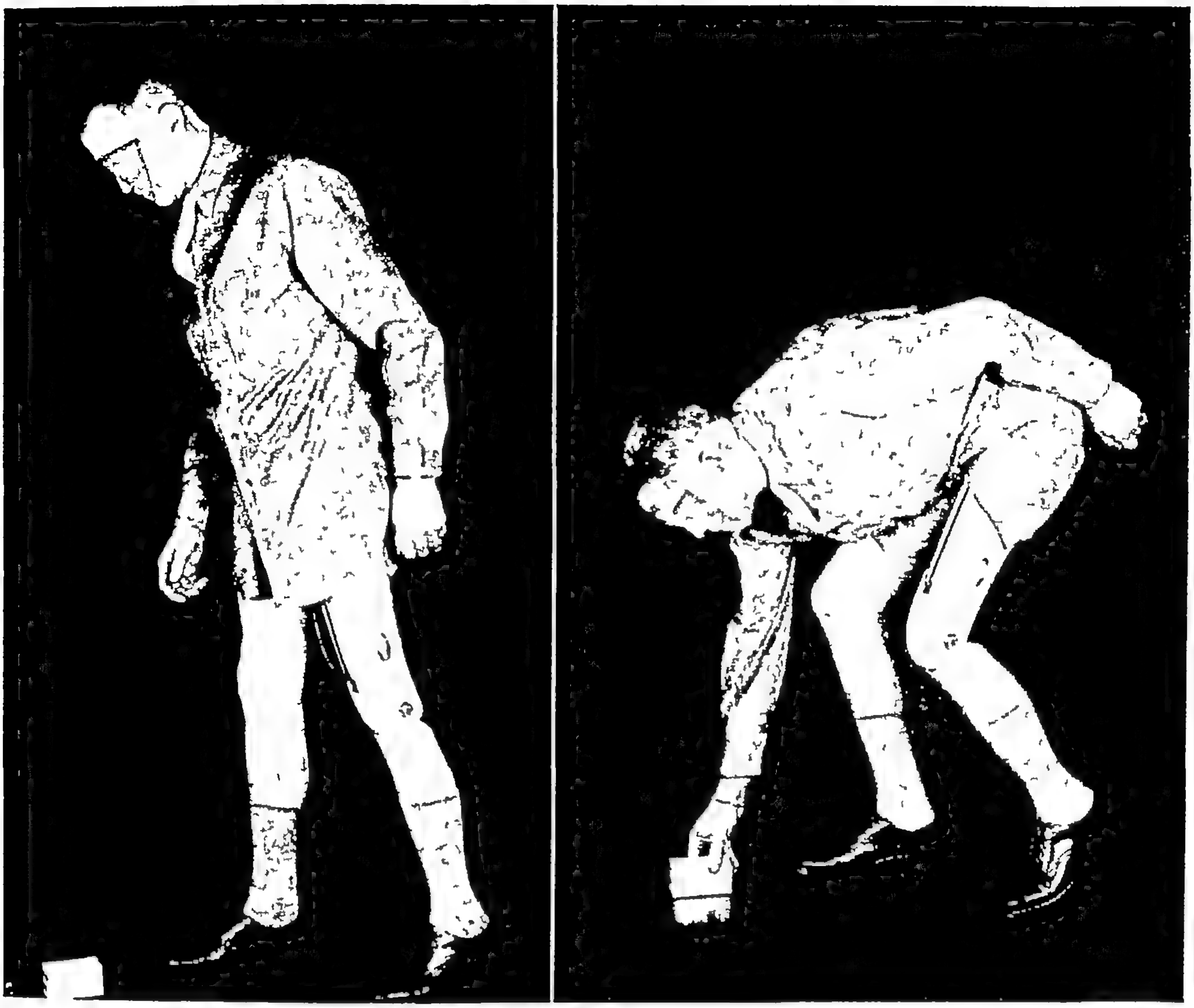
(1) *Unilateral* As shown in Fig 514, *A* the prosthesis is advanced slightly ahead of the normal foot While bearing the body weight principally on the normal leg, the patient bends from the waist and stoops, picking up the object as in Fig 514, *B*

(2) *Bilateral* Employ the same technique as for b(1) below, bearing the body weight on the leg which seems stronger to the patient

b THE ABOVE-KNEE AMPUTEE

(1) *Unilateral* The normal leg is advanced approximately a half a step ahead of the prosthesis as shown in Fig 515, *A* While bearing the body weight on the normal leg, the patient bends from the hips, flexing the thighs and legs to pick up the object as shown in Fig 515, *B*

(2) *Bilateral* Stooping for an object in the case of the bilateral amputee is difficult but not impossible to accomplish, it requires rather exceptional strength of the musculature of the shoulder girdle, forearm extensors, and finger flexors The patient stands approximately 12 inches behind the object, placing the suction-type, rubber-tipped cane well forward to brace himself as shown in Fig 516, *A* He then rocks back on his heels and, while maintaining his balance on the extended prostheses and the cane, he reaches for the object as shown in Fig 516, B After grasping the object, the erect position is assumed by pushing up strongly against the cane, bringing the cane toward the body by short, quick steps



A *B*

Fig 515—Stooping Unilateral, above knee amputee

A, Place the normal foot approximately half a step ahead of the prosthesis Shift the body weight to the normal foot

B, Bend from the waist, bearing the body weight on the normal foot, flex the thighs and knees, and grasp the object

(Walter Reed General Hospital Neg No 4010 A19, A18)

8 **Curbs**

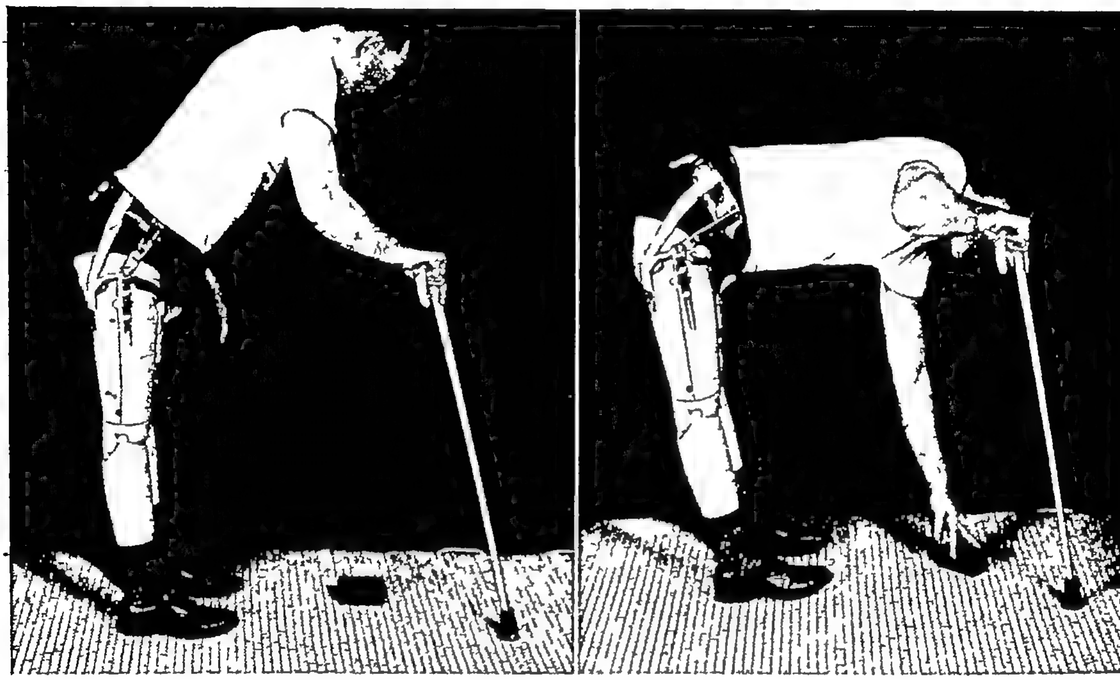
a THE BELOW-KNEE AMPUTEE

(1) *Unilateral* This individual should experience no difficulty in placing either foot on the curb and stepping up

(2) *Bilateral* Employ the same technique as illustrated in Fig 517

b THE ABOVE-KNEE AMPUTEE

(1) *Unilateral* Practice taking the curb in the normal stride Referring to Fig 517, as the curb is approached, place the prosthesis heel on the curb, extend the thigh, and push off strongly with the normal foot, permitting the momentum of the body to maintain the prosthesis knee in extension as the weight is borne briefly on it Step forward with the normal foot



A *B*

Fig 516—Stooping Bilateral, above knee amputee

A, Stand approximately 12 inches away from the object Place the suction tipped cane well forward for support Bend forward from the hips

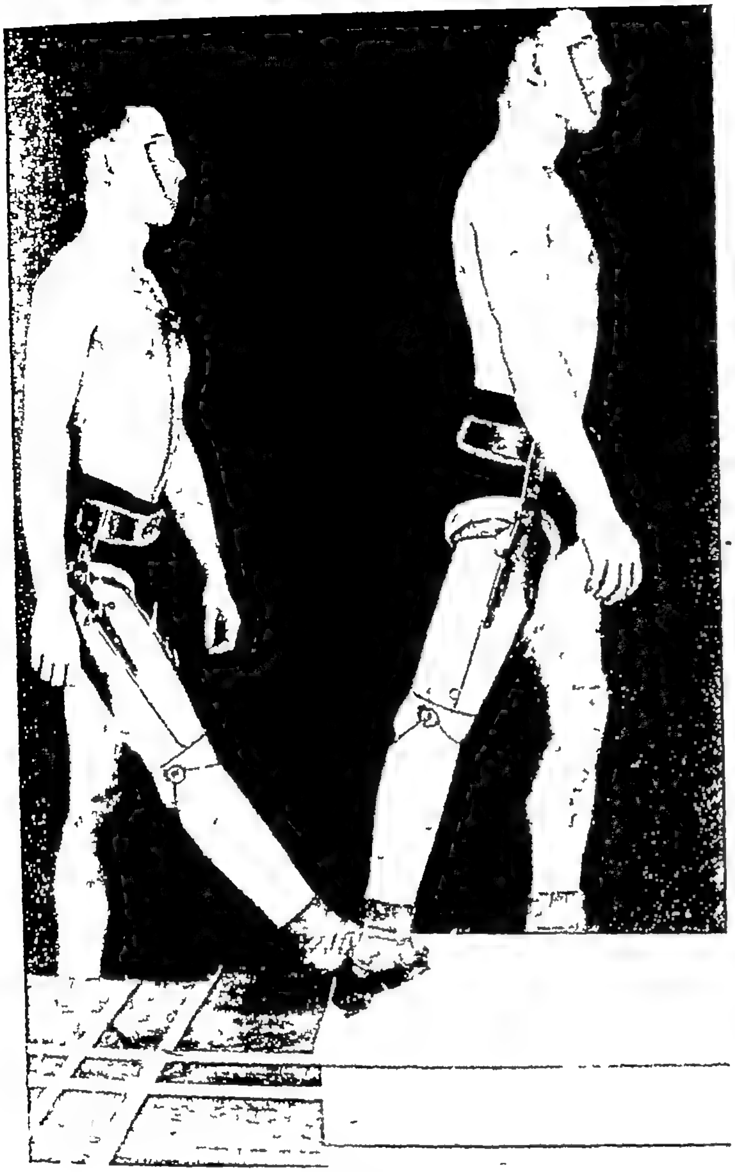
B, As forward bending continues, rock back on the heels to maintain extension of the legs, and reach for the object Steady self with the cane The erect position is gained by pushing upward on the cane, then bringing it toward the body by quick, short steps

(Walter Reed General Hospital Neg No 4746 A14, A15)

To descend from a curb, bear the body weight on the normal extremity and step down with the prosthesis Extend the prosthesis knee, shift the body weight to the prosthesis, and step down with the normal foot

(2) *Bilateral* It is usually not possible for the bilateral amputee to step up onto a curb unless a railing or support of some type is available As shown in Fig 518, there is no normal foot to provide the push-off necessary to ascend the curb, nor is there any means of breaking the body's momentum, and if by chance the curb could be ascended both prosthesis knees would flex and the patient would fall If a curb must be ascended, it may be accomplished in the same fashion as though it were a single step, as shown in Fig 511

9 **Sitting on Floor** The acquisition of skill in sitting on and rising from the floor is valuable These activities are not necessarily a part of the daily



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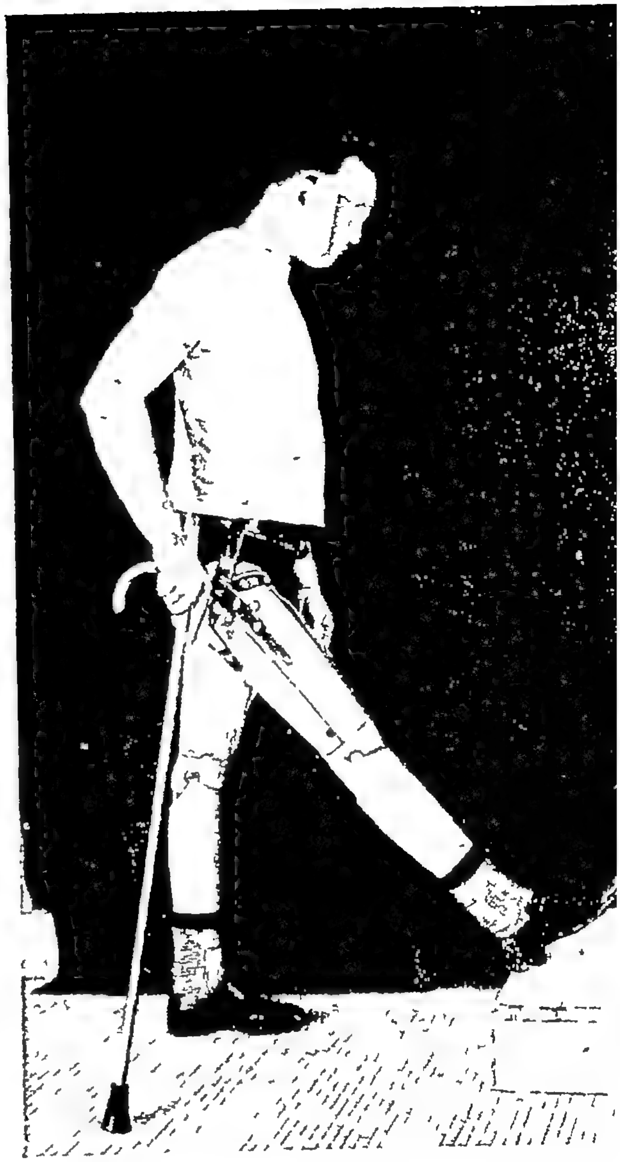


518

Fig 517 —Ascending curb Unilateral amputee

Place the prosthesis heel on the curb, extend the thigh, push off strongly with the normal foot, recovering from this momentum with a step forward with the normal foot (Walter Reed General Hospital Neg No 4542 A27)

Fig 518 —Ascending curb Bilateral amputee

Unless there is a railing for ascending the curb in a fashion similar to ascending stairs (Fig 511), it is not possible for the bilateral amputee to accomplish this successfully There is no normal foot to provide the necessary push off nor is there means for stopping the momentum gained in ascending the curb as in Fig 517 (Walter Reed General Hospital Neg No 4746 A12)

routine, but the elective performance of such acts is frequently desirable and, in the event of a fall, the individual must know how to regain his feet without difficulty

a THE BELOW-KNEE AMPUTEE

Unilateral and bilateral amputees may follow the steps described under b(1)

b THE ABOVE-KNEE AMPUTEE

(1) *Unilateral* In this sequence it is helpful for the patient to regard himself as in the center of an imaginary clock face, facing the position of 12 o'clock For a right thigh amputation, the right leg is advanced slightly, the body weight is borne on the left leg and the individual half turns to the left as shown in Fig 519 As he lowers his weight, the left hand is placed on the floor with the forearm firmly extended This sequence should be practiced as one continuous movement so that the body weight will be borne progressively by the left leg left upper extremity, and gluteal region

Fig 519—Sitting on the floor Unilateral amputee

Place the prosthesis a half step forward, bear the body weight on the normal foot, half turn toward the left (normal) side, flex knees and thighs, reach for the floor at the position corresponding to 8 o'clock on a clock face, and gently lower self to the floor (Walter Reed General Hospital Neg No 4542-A26)

(2) *Bilateral* The suction-type, rubber-tipped cane is placed approximately 18 inches ahead of the feet, the patient rocks back on his heels to maintain the prostheses knees in extension, bends forward from the waist and reaches toward the position of 10 o'clock as he maintains balance with the cane This

A

B

C

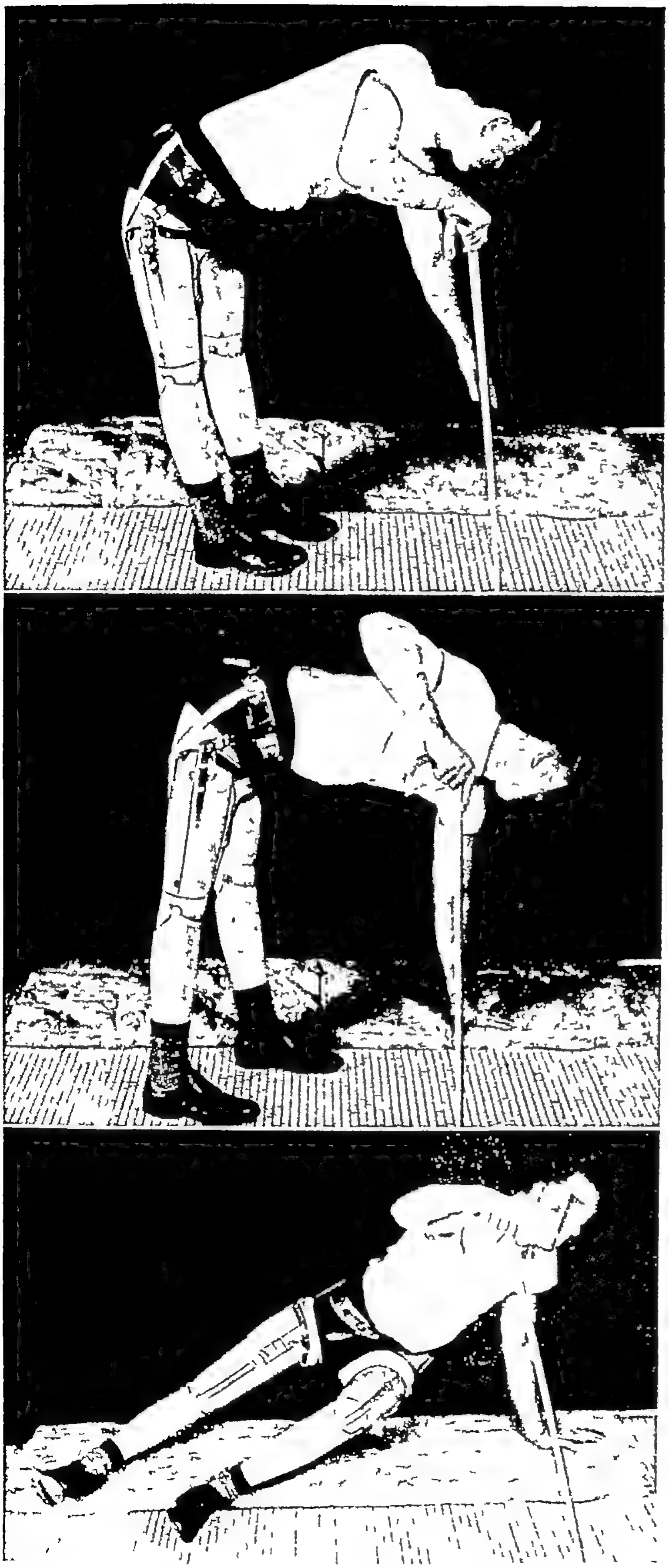


Fig 520—Sitting on floor Bilateral amputee

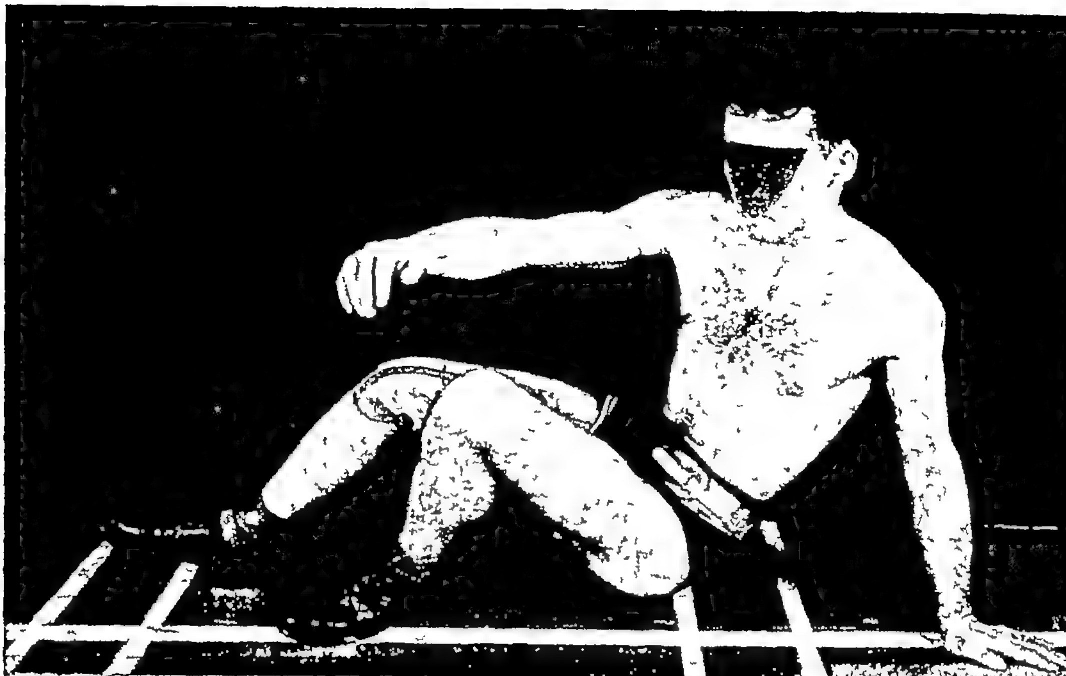
A, Place the cane tip firmly on the floor about 18 inches ahead of the feet Rock back slightly on the heels Bend forward from the waist Reach for the floor in the relative position of 10 o'clock on the clock face

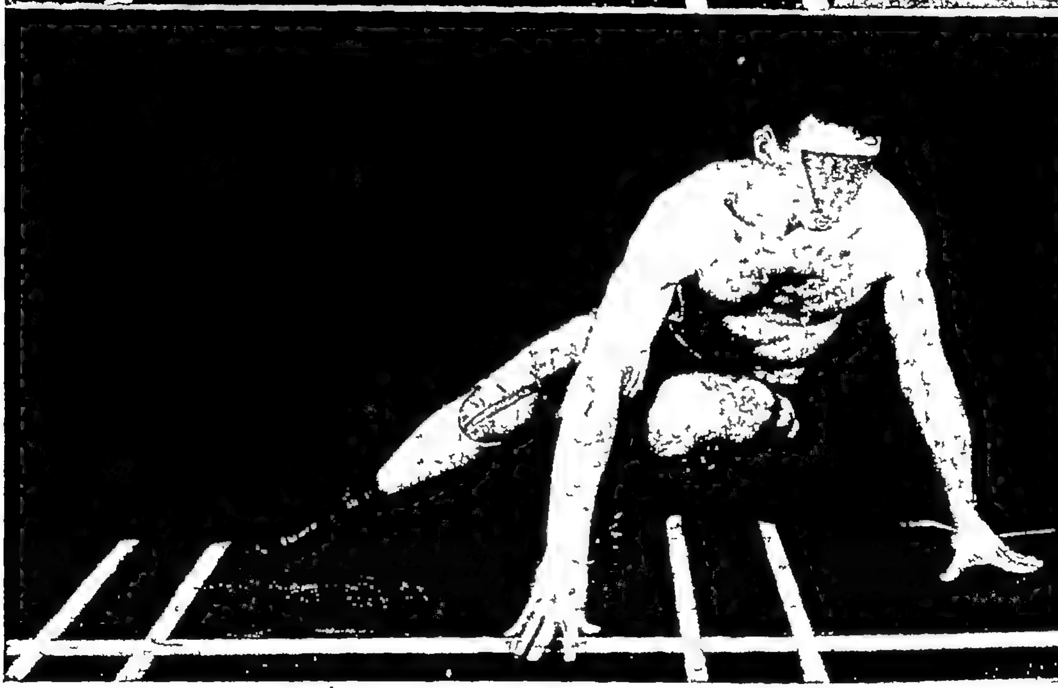
B, As the left hand contacts the floor, shift the body weight to the left prosthesis Maintain equilibrium by the upper and left lower extremities Keep the right prosthesis extended

C, Flex the left thigh and pivot to the left Control of descent is assured by the left upper extremity and the adductors of the right lower extremity

(Walter Reed General Hospital Neg No 4746 A22, A21, A5)

A





B

Fig 521 —Rising from the floor Unilateral amputee

A, Bring the normal (left) leg well under the body Place the left hand behind the body at a position corresponding to 7 or 8 o'clock on a clock face Pivot to the left strongly and push up with the left arm and leg Stability of equilibrium is maintained with the semi flexed prosthesis leg

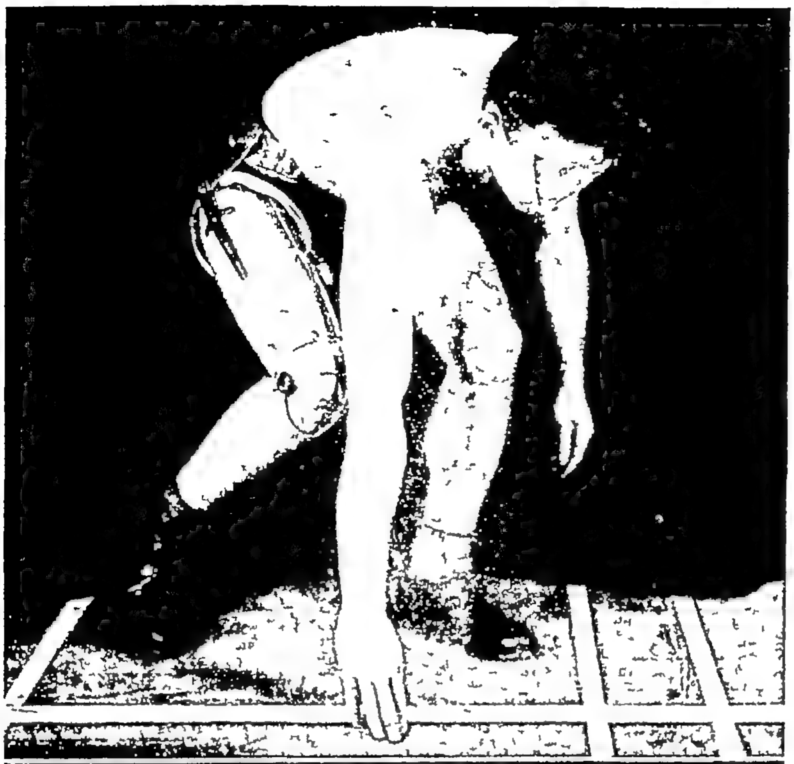
B, The pivot movement continues about the left foot until the right hand is now in contact with the floor at the relative position of 11 o'clock and the left (normal) foot is immediately under the body

C, The individual pushes up strongly with both hands, bearing the body weight on the left (normal) foot The right hand remains in contact with the floor during the early phase of rising to avoid the tendency to fall toward the prosthesis side

D, As the erect posture is gained, the prosthesis is extended and forward walking is begun with the normal foot

(Walter Reed General Hospital Neg No 4542 A22, A21, A19, A26)

C



D

Fig 521 *(For legend see opposite page)*

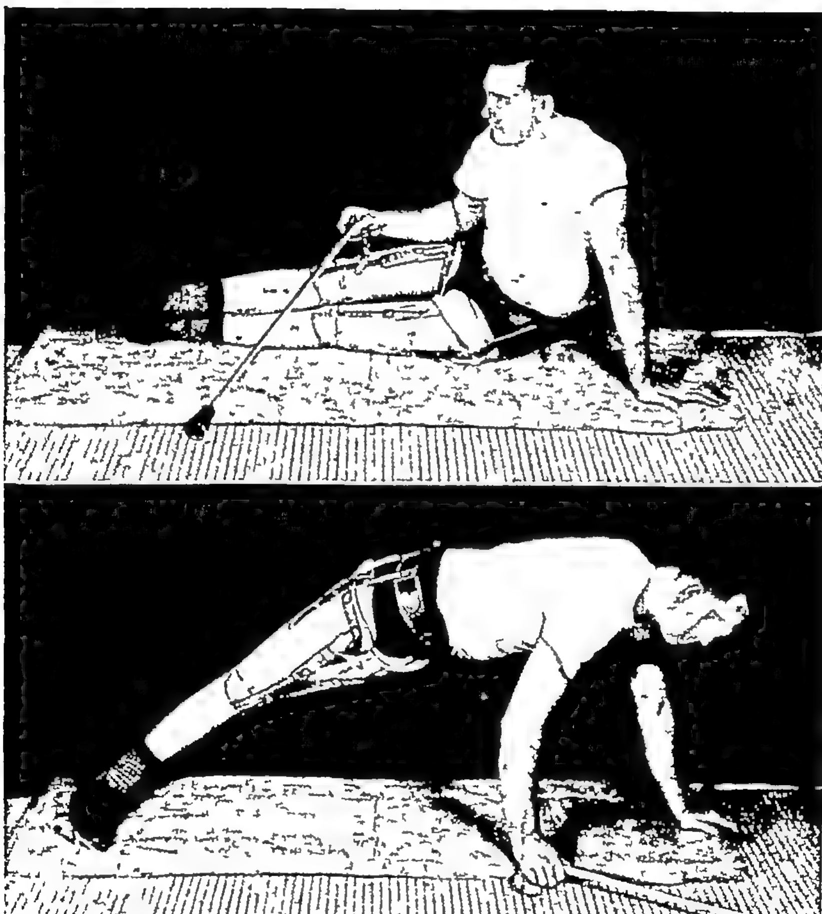
position is illustrated in Fig 520, *A* After the left hand contacts the floor, the body weight is shifted to the left prosthesis as the right lower extremity is extended slightly as shown in Fig 520, *B*, equilibrium is maintained with the left lower and both upper extremities The left thigh is then flexed as the lower trunk is pivoted to the left The descent to the floor is not forcible, since weight can be borne laterally on the flexed left prosthesis and the left upper extremity

10 **Rising From the Floor**

a The Below-Knee Amputee

Both unilateral and bilateral amputees may follow the sequence described under b(1)

A



B

Fig 522—Rising from the floor Bilateral amputee

A, The right prosthesis is lifted and crossed over the left The left upper extremity is extended and placed at the relative position of 8 o'clock The cane is brought across the body well to the left side The individual begins to pivot to the left

B, As the pivot to the left continues, push up strongly with both hands, bracing self against the sides of the extended prostheses Keep pressure against the toes of the shoes to maintain extension of the prostheses

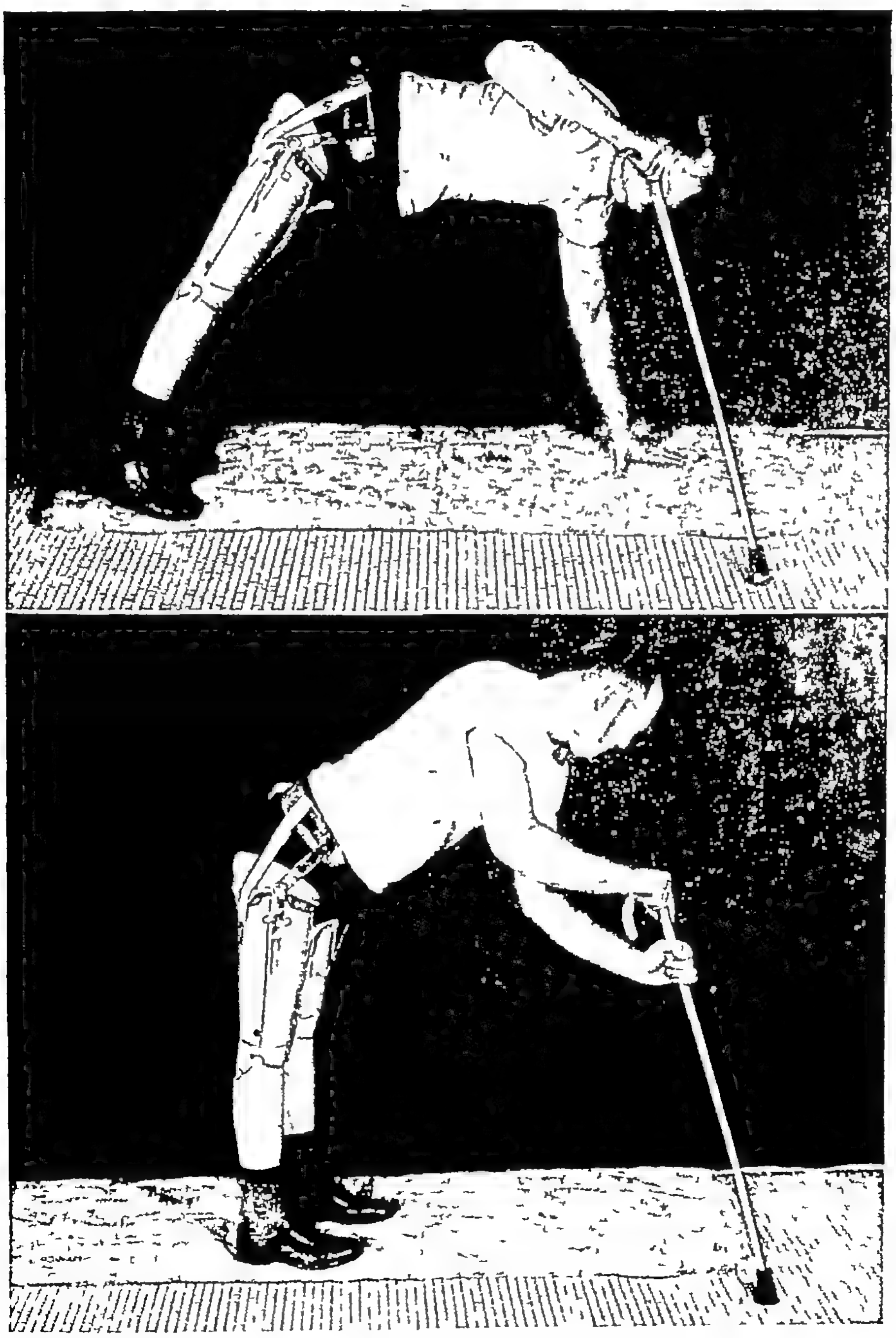
C, The cane tip is now firmly braced against the floor and the torso is thrust upward by the strength of the upper extremities Continue the pressure against the toes of the shoes

D, The left hand now grasps the cane also, and the erect position is assumed by first "climbing up" the cane and then bringing the cane toward the body by quick, short steps

(Walter Reed General Hospital Neg No 4746 A4, A7, A6, A9)

(1) *Unilateral* The normal (left) leg is flexed to 90 degrees and ~~the sole~~ JA of the shoe is placed firmly on the floor The left hand, with the forearm firmly extended, is placed in a position of 8 o'clock As the patient pivots the body strongly to the left, pushing off with the right arm if necessary, the right arm is swung across the body toward the position of 11 o'clock as the weight is borne on the left leg and the patient begins to rise from the floor, this initial position is illustrated in Fig 521, *A* With both hands firmly in contact with the floor, he pushes off strongly with the forearms and continues to rise, as shown in Fig 521, *B* To facilitate standing, the right hand remains in contact with the floor to ensure equilibrium as shown in Fig 521, *C*, the body weight is still borne on

C



D

Fig 522 *(For legend see opposite page)*

the left lower extremity As the erect posture is gained, the right (prosthesis) thigh is extended and the patient is in normal walking position as shown in Fig 521, *D*

(2) *Bilateral* Rising from the floor is more difficult for the bilateral amputee, but by no means is it an impossible achievement From inspection of the illustrations comprising Fig 522, it is obvious that rather marked muscular development of the upper trunk and upper extremities is necessary for the accomplishment of the procedure With the individual sitting and both legs extended the knees are locked in extension, the right leg is crossed over the left and the body is pivoted toward the left as shown in Fig 522, *A* The twist of the upper torso continues until the patient can place both hands on the floor in the position of 6 and 9 o'clock By pushing up strongly with both forearms and maintaining both prostheses in extension, rising can be initiated as shown in Fig 522, *B* As the lower torso takes up the pivoting motion, the balls of the feet are maintained in contact with the floor in order to ensure extension of the prostheses knees The cane grasped in the right hand is now placed firmly in contact with the floor and the patient begins to push himself up and backward toward the extended prostheses as shown in Fig 522, *C* The erect position is assumed by "climbing up" the cane with the left hand, as shown in Fig 522, *D*, and finally by bringing the cane toward the body by quick, short steps The thrust upward from the position of Fig 522, *C* must not be so strong that the individual will immediately attain the erect position, to do so will result in momentary loss of equilibrium as the weight-bearing is suddenly shifted from the balls of the feet to the heels, and the knees will usually buckle

11 Ascending an Incline

a THE BELOW-KNEE AMPUTEE

(1) The unilateral amputee should experience no difficulty with this procedure

(2) The bilateral amputee usually finds it necessary to shorten the length of stride and to walk on the balls of his feet Difficulty is seldom encountered otherwise

b THE ABOVE-KNEE AMPUTEE

(1) *Unilateral*

(a) Slight inclines may be ascended by shortening the length of each step and by walking on the balls of both feet

(b) Moderate inclines are best ascended in diagonal fashion whenever possible Steps should be as long as consistent with stability of equilibrium, weight should be borne on the balls of both feet, and ascent should be with the normal leg on the uphill side

(c) Steep inclines or slopes in which diagonal uphill walking cannot be employed should be ascended by side steps The sequence should be With normal leg toward the uphill side, shift the weight to the fully extended prosthesis, take a side step with the normal leg, shift the weight to the normal leg raising the body to the higher level, and adduct the prosthesis to a position beside it, repeat the sequence for additional steps

(2) *Bilateral*

(a) Slight inclines are ascended without difficulty by shortening the length of steps, walking on the balls of the feet, and by carrying the canes or crutches well forward to insure stability of equilibrium

(b) Moderate or steep inclines are best ascended sideways The prosthesis knee on the downhill side must be locked in extension Assume that this is the left leg Bear the body weight on the left leg and the right cane or crutch Flex and abduct the right thigh, extend the leg and bear the body weight on it and both canes Adduct the left (downhill) prosthesis to a position beside the right leg

12 **Descending an Incline**

a THE BELOW-KNEE AMPUTEE

(1) *Unilateral* Provided that there is good quadriceps strength of the involved side, descent should be accomplished without difficulty If the quadriceps is weak, the knee will tend to buckle as weight is borne on it Although the proper remedy for this defect is strengthening the quadriceps, until this is accomplished it is permissible to practice descent by taking a short step with the prosthesis, shifting the weight to it as the body moves forward, and recovering equilibrium with the normal leg in the same fashion as the above-knee amputee descends steps Railing or support should be employed until confidence in this procedure has been established

(2) *Bilateral* If the strength of the quadriceps is good, the bilateral amputee can descend the incline without difficulty If the quadriceps are weak, support should be provided either by railing or canes, not only to assist in maintaining equilibrium but also to slow down the steps so that he does not have to run down the slope For steeper declines, this is especially important since the individual has less secure control over the prosthesis than does the unilateral amputee

b THE ABOVE-KNEE AMPUTEE

(1) *Unilateral*

(a) Slight inclines may be descended by taking each step alternately as in descending steps If the amputation stump is short, it is permissible to take a short step with the prosthesis to avoid buckling of the knee otherwise frequently encountered with longer steps

(b) Steeper slopes may be descended either in diagonal fashion with the normal leg toward the uphill side or by single steps In the latter instance, the patient should step down with the prosthesis, extend the prosthesis knee and bear the body weight on the prosthesis heel as the normal leg is brought down beside it

(c) Very steep slopes should be descended sideways with the normal leg toward the uphill side Step down with the extended prosthesis, shift the body weight to it, and bring the normal leg down beside it Shift the weight to the normal leg and repeat the sequence

(2) *Bilateral* Unless the decline is very slight, the bilateral amputee will require support to prevent his momentum from carrying him beyond his ability to stabilize the prosthesis in extension long enough to permit weight-bearing Usually if he places his hand on the shoulder of another individual, no other support is needed The technique described under b(1)(b) above may be followed in general Lock the right knee in extension and step down with this leg, bearing the weight on the right heel and insuring stability of equilibrium by placing a hand on another person s shoulder or by the canes The left knee will automatically flex as the weight is transferred to the right prosthesis Bring the left prosthesis down beside the right Repeat the sequence

Comment

It is realized that the suggestions offered in this section do not constitute complete training in the use of the present-day lower extremity prosthesis. They do cover the commonplace daily activities. The amputee who masters these activities will seldom experience difficulty when others are encountered. The instructor who routinely attempts to cover all phases of amputee training will usually find that his efforts either have been spread over so many procedures or are so multitudinous in their detail that the patient has not grasped or mastered the procedures fundamental to skillful use of the prosthesis. Professional responsibility has largely been discharged when the patient can successfully utilize the prosthesis in his day's work. It is hoped that each amputee will have many years in which to perfect all the other details of ambulatory activity.

XII. PHYSICAL REHABILITATION OF THE UPPER EXTREMITY AMPUTEE

Physical rehabilitation is a vital part of the care of the amputee This is especially true when the limb lost is an upper extremity, for, in this instance, the patient's physical independence and economic welfare depend upon it He has lost one of the most functional tools of the body, the hand, and if he is to care and provide for himself, he must alter the habit patterns of a lifetime, he must learn to accomplish the most ordinary tasks and many special skills single-handed or with a prosthesis If he possesses normal coordination and mental qualifications, and has the perseverance and the desire to learn, thoughtful training in the use of the normal hand and of the prosthetic arm will enable him to face the world self-reliant and physically independent of others Actually, physical rehabilitation does far more than fulfill its immediate purpose, it is, in addition, the greatest contributing factor toward ultimate psychological readjustment The diversion of the work involved takes the patient's mind from his own troubles and affliction, and aids greatly in diminishing his self-consciousness As his proficiency increases, he will find that he is capable of doing practically anything required of him, if he does it in his own way Thus, his self-confidence is restored, and he will soon come to look upon himself as a normal individual who has lost a limb, and not as a cripple

The kind of training required for physical rehabilitation is determined by the situation the level of the amputation, the matter of handedness, and of course, the patient's mental capabilities and willingness to learn

The level of amputation is significant because it determines the type of prosthetic arm to be worn Unfortunately, scientific research has not yet proved an artificial hand which is both functional and cosmetic The hook offends the esthetic senses and is, at best, a poor substitute for the normal hand, but it is functional, and the below-elbow amputee should be encouraged to wear it and taught to use it dexterously For the above-elbow amputee, however, this device is less discriminatory in action It is, therefore, of little value to him in definitive skills but is useful chiefly as an assistant For the amputee with the very short above-elbow stump or for the one upon whom shoulder disarticulation has been performed, the functional value of a prosthesis is negligible He may wear an artificial arm with gloved hand for the sake of cosmesis, but is more likely to discard even this as cumbersome Obviously, in all above-elbow amputees training of the normal arm should be stressed When bilateral amputation has been carried out, there is usually no question as to the wearing of a functional prosthesis, since without it the patient is absolutely unable to take care of himself without considerable help from his friends or family

The matter of handedness must next be considered before training is begun For the sake of clarification, it should be noted here that the term "major arm"

or "major hand" is used to signify that extremity which was naturally dominant prior to amputation, while the idiom "minor arm" or "minor hand" denotes that which was subordinate. Handedness determines the type of training to be undertaken. Upon this basis it is established whether the emphasis should lie on the training of the prosthetic arm or upon that of the remaining normal hand. It is a waste of time, and is often disturbing to the patient, to attempt to train the prosthetic arm in definitive tasks when the major arm is intact and will naturally assume these functions. On the other hand, however, it is equally futile to train the normal minor hand to perform all skills singlehanded, when a patient can wear a functional major arm prosthesis and is capable of learning to use it as an assistant in bimanual tasks. In short, the surgeon should analyze what there is to work with and set the program of training accordingly. (1) When the major arm remains, the problem is relatively simple. The normal major hand will naturally carry out those skills performed by one hand, but in the bimanual tasks a readjustment must be made, for the dominant hand has been deprived of its normal partner. Although the minor prosthetic hand will substitute for this, there may be times when it is not worn, and for this reason it is advisable to develop the dexterity of the major hand so that it can perform alone such bimanual tasks as tying the shoe, buttoning buttons, etc. As to the minor prosthetic arm, the patient need only be taught to use it as a partner. (2) When the minor hand remains, the problem is more complex. The extent of the training of the normal hand and the extent of the training in the use of the prosthesis both depend upon the natural inclination of the patient. For some, the normal minor hand will assume all one-handed skills, and must, therefore, be taught the role of leader rather than its natural one of assistant. With these patients the emphasis should lie on thorough training of the normal hand, although they should learn to use the prosthesis as an aid adjunct. For others, learning to perform tasks with a major arm prosthesis will be more natural and more easily done than transferring those functions to the minor hand. These patients will require more intensive training in the use of the artificial arm, but they, too, should develop the coordination of the normal hand for there are some fine discriminatory tasks for which it must be used because of its sensation and dexterity.

Much may be done toward the physical rehabilitation of the amputee during the preprosthetic period, that is, the period before he receives his artificial arm. Almost immediately after his amputation, he can begin to develop his remaining normal hand, and he should be taught at that time the various "tricks of the trade" which will enable him to perform the bimanual tasks singlehandedly. If it is the minor hand which remains, there are any number of activities, such as darts, weaving, tooling, modeling, typing, carpentry, etc., which will greatly increase its dexterity and coordination and minimize its awkwardness. This training is of particular importance when the major arm has been amputated above the elbow and a truly functional prosthesis is not anticipated. Later on in this period, if there are no secondary wounds upon the stump, a cuff may be applied to it and the patient may be taught such skills as ping-pong and writing which will be of value to him in learning to control and use the prosthesis.

After the prosthetic arm has been acquired and the stump is ready to assume it, training has a dual purpose: (1) to teach the patient how to use the prosthesis, and (2) to check the construction and fit of the prosthesis under actual working conditions. The activities employed for training at this time are more valuable if they are made interesting and if they allow the patient to explore for himself the possibilities of the artificial arm. Amputation checkers is a valuable adjunct to this early training. It is played on a checkerboard

approximately two feet square, using checkers of various sizes, shapes, and weights. The board is made purposely large so that the patient in reaching to its far side learns to use the hook both close to the body and at some distance, and in doing so comes to appreciate the relation of the opposite shoulder to the function of the prosthesis. For example, he finds that the hook when moved forward by the stump automatically opens and can only be closed by allowing the opposite shoulder to fall backward. In addition to teaching the amputee how to use the arm or hook, an intelligent instructor will also note the length of the pull cord and general use of the limb in order to inform the limb mechanic of any defects.

Once the fundamentals of the prosthesis are understood by the patient, the scope of his training should be broadened to include a knowledge of the value of the prosthesis as a partner to the normal hand. Even though the amputee may find that he can perform most tasks more easily with the normal hand, there will still be many occasions when assistance is needed, and in such partnership activity the prosthetic hand is invaluable. Examples of this are holding a piece of paper during writing, holding a package of cigarettes while one is withdrawn, etc.

In the preliminary stages of training, such activities as carpentry, cord knotting, weaving, etc., are effective in developing coordination between the prosthetic and the normal hand. However, as the patient shows progress, overemphasis on skills which have no future usefulness will make him lose interest and become desultory in his training. It is best to avoid this by starting work therapy and vocational training as soon as possible.

The training discussed thus far has had as its aim the increased dexterity of the normal hand, the skillful use of the prosthesis, and the coordinated function of the two as a partnership. Physical rehabilitation of the amputee, however, will not be complete until he has learned to accomplish by himself the everyday tasks with which he will be faced. Through his instructor he has the opportunity of profiting by the experience of others, and while under his tutelage should learn the tried and proved methods of performing specific chores with the handicap of an amputation. Many of these may be taught him while he is awaiting the prosthesis (in fact, should be taught him whether or not he expects to wear an artificial limb), and those to which immediate attention should be directed are the ones concerned with personal hygiene and dressing. The ingenious amputee will often devise new methods of his own, or improve upon those which he has learned. Following are certain pointers which may aid him in learning to care for his person.

1. **Washing and bathing.** The hands and nails can be cleaned thoroughly by means of a nailbrush. Two small suction cups incorporated in its back will hold the brush fast while the hand is rubbed across it. If this is not available, a large washcloth may be well soaped and placed over the edge of the basin, and the hand and arm rubbed over it in all directions. This may also be adapted to bath tub use by placing the cloth over the knee. In this way not only the hand and arm but also the axilla and back of the shoulder can be bathed. A long handled brush is usually used to reach the back. There are special bathing aids for the bilateral amputee, one of the most generally accepted being the cone covered with a sponge which fits loosely over the forearm stump.

2. **Trimming the nails.** The simplest way to trim the nails is to use a long nail file, preferably the ten inch size, and to pass the fingernails over its surface until the desired shape and length is obtained. The trick to this operation

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Fig 523 —Use of the nailbrush fitted with two small suction cups (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

Fig 524 —The nailbrush without suction cups may be used in this manner to cleanse the normal hand and arm when a functional prosthesis is worn Illustrated also is the manner of holding the nail file with the hook The file may be stabilized by the belt buckle, vamp of the shoe, etc., if the hook is not used (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

is to stabilize the file This may be done by placing it beneath the stump, under the vamp of the shoe, or under the buckle of the belt, if the roller-type buckle is worn Some amputees prefer a nail clipper, but its use is somewhat awkward as the clipper must be placed on a flat surface, and the opposite foot used to press the lever which closes the jaws of the clipper around the nail

3 **Shaving** Shaving requires no special technique If the beard is tough, the skin may be tightened by turning the head to tighten the skin on the neck, moving the jaw or filling the cheek up with air Many amputees prefer to use the electric razor This is especially true for the bilateral

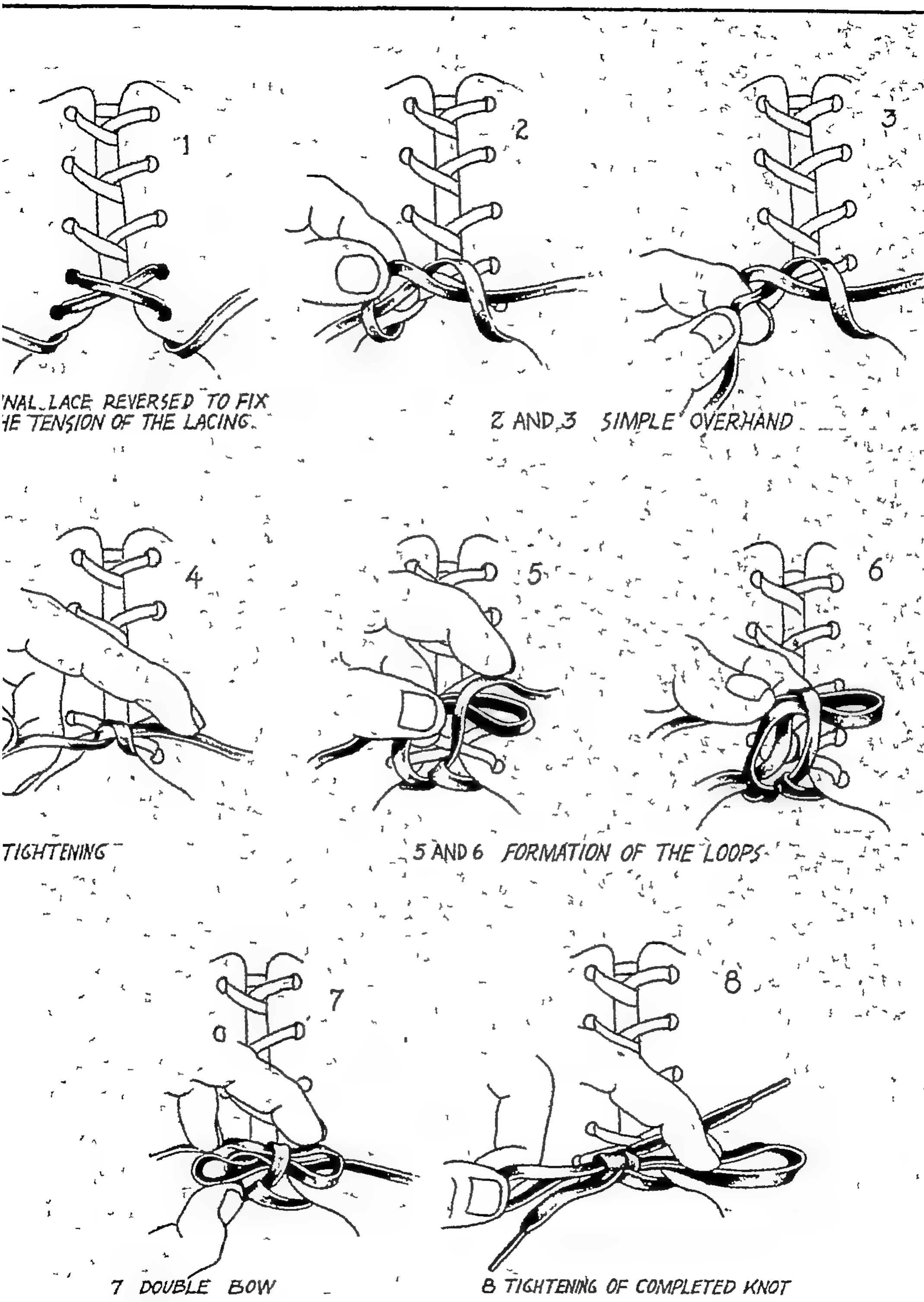
4 **Using the bathroom** presents a problem to the bilateral amputee which is always distressing at first This may be solved by taking a large amount of toilet tissue and wrapping it around the hook

5 **Tying the shoe** It is not difficult for the amputee to slip the shoe on the foot and lace it, but tying the knot singlehanded is not easy There are several systems, any one of which can be done successfully after a little practice Following are two one-hand methods commonly used In both it is important that the laces be anchored securely at the top of the vamp to keep them from slipping when the loops are pulled tight, and to ensure a firmly laced shoe This may be done by passing them through the upper eyelets a second time or by running them through these eyelets in reverse—from the top side of the shoe inward toward the foot

Double loop bow To avoid confusion in this description, it will be assumed that it is the left shoe which is being tied by the left hand, though the method is equally adaptable to the right foot and right hand, left foot and right hand, and so forth The lace from the inside eyelet is placed diagonally over the shoe and the outer lace looped over it The lace now lying on the inner aspect will be called the right lace, and that on the outer the left lace The shoestrings are pulled taut by pressing the right one against the shoe with the index finger and pulling the left one with the thumb and ring finger The right lace is then held by the toe of the other shoe while the thumb and last two fingers form a loop of the left lace Next the right lace is released by the opposite foot and the index finger is used to bring it around the loop and through in the ordinary manner to form a second loop The left loop is now grasped by the thumb and ring finger while the right one is extended by the index finger, pulling the double bow tight

Two single loop bows For many this method is more easily learned It consists of two single loop bows, one on top of the other, and when completed looks like a conventional bow knot The inside lace is placed across the shoe and the other is brought over and around it in the usual manner The lace now lying to the left is grasped by the little and ring fingers The right one is taken by the thumb, middle, and index fingers, looped around the other, brought through, and tightened into a single bow A second bow is now made on top of the first by carrying the longer, left lace around the first bow and pulling the loop through tightly

6 **Tying the necktie** A necktie may be tied by one hand in the following manner After the tie is placed around the neck and under the collar, the long portion is passed around the shorter portion one and a half times Then, with the short portion held between the fourth and fifth fingers, the long piece is forced upward under the twist with the thumb It is caught by the index finger and drawn on over to lie on top of the shorter piece The knot is then loosened slightly in order that the long, wide portion of the necktie can be forced downward through the loop by the thumb and index finger The knot is then tight-



ONE-HAND METHOD OF KNOT TYING FOR THE AMPUTEE

Fig 525

ened by grasping the long underneath piece in the middle, ring, and little fingers and forcing the knot upward to the collar by the thumb and index finger

7 **Buttoning and unbuttoning** The upper extremity amputee can usually manage the buttons along the front of the body with ease but frequently has trouble with those on the sleeves The buttoning of these is best done before the shirt is donned The unbuttoning can be accomplished by using the teeth to grasp and pull the edge of the cuff As this is done, the button spreads the buttonhole and slips through Some may wish to facilitate the process of buttoning by the use of a wide buttonhook or wire loop In the cases of the bilateral amputee some such device is imperative

If a prosthesis is not worn, the empty sleeve of the coat should be pinned in the pocket or pinned to itself It may be inverted into the body of the coat, but when this is done, there is likely to be too much bulk for the wearer's convenience Often shirts, night clothes, etc, are better short-sleeved

Due attention should also be given to everyday tasks other than those concerned with personal care As soon as possible, the upper extremity amputee should begin to receive instruction in writing, use of the telephone, etc

Writing When the major arm remains, it will not be necessary for the amputee to learn to write all over again However, it will be found that there is a tendency to enlarge the characters because of the lack of ability to hold the paper This may be remedied by the use of a paperweight or by learning to hold the paper with the last three fingers while writing with the thumb and index finger The latter method tires the hand quickly, and, therefore, is useful only when a few lines are to be written It is well worth the amputee's while, however, to learn this so that he will not be at a loss when no paperweight is at hand When a paperweight is chosen, it is preferable to select one which weighs at least two pounds There is an excellent type which measures 11 to 14 inches in length by about two inches in width, and three-fourths of an inch in height It is surmounted by a handle and has a sharp edge along the bottom of the front side which makes it possible to tear off paper when desired

When the remaining hand is the minor one, however, the patient must learn to write again If a functional prosthesis is not anticipated, the minor hand will, of course, assume this task, but when the stump is such that a hook will be worn, the question arises—shall the amputee be taught to write with his remaining minor arm or with the hook which will substitute for the major hand? There are two schools of thought on this subject One believes that the function of writing should be transferred to the minor hand, and bases this conviction on two premises (1) the process of re-education may be begun immediately following amputation, and (2) it is better to recognize the need for retraining around the disability, than to attempt the training of the prosthesis in the more definitive skills An individual who learns to write with the minor hand is usually able to do so legibly with practice though normal speed is seldom attained The other school of thought maintains that the amputee should be taught to write with the major prosthesis, and it bases this opinion on the fact that the transference of handedness necessitates a change of brain pattern, which may have deleterious psychological effects In addition, proponents of this theory aver that writing with the major stump is more quickly learned, and that its speed and naturalness is superior to minor-hand writing because it follows the normal pattern already established However there are certain disadvantages (1) With the stump above the upper third of the forearm, even though it is capable of supporting a functional

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Figs 526 and 527—A necktie may be tied with one hand if necessary, but is more simply tied with hand and hook The hook is used to stabilize the short end of the tie and to thread the loop (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

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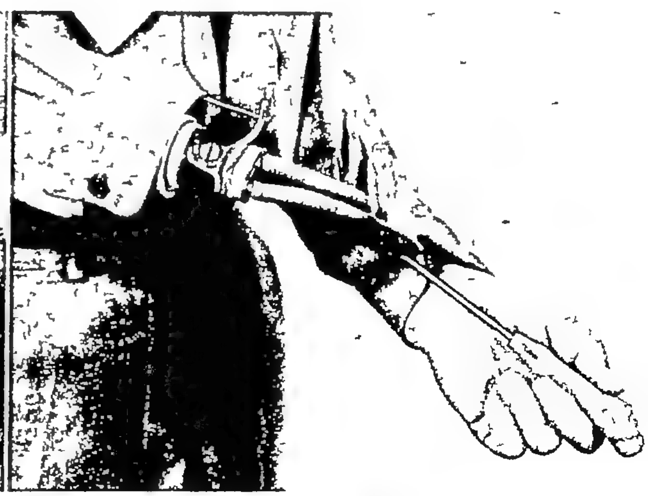

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Figs 528 and 529—A buttonhook is used to button the cuff of the shirt For ease in buttoning buttonholes are often made somewhat larger than normal (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

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Fig 530—The use of the zipper on shirt, coat, and pants makes dressing easier for the amputee The prosthesis stabilizes the lower portion of the shirt while the normal hand draws the fastener upward Insert shows method of starting the fastener with one hand Flat hooks are used by many in place of zippers or buttons (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

Fig 531—The hook is used to place a glove on the normal hand (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

prosthesis, control is lessened and writing will always be difficult (2) Instruction must necessarily be delayed until the stump is no longer painful and any secondary wounds upon it are healed so that a device for holding the pencil may be strapped to it When the stump is short, as mentioned above, training cannot be started until the prosthesis is assumed, for there is not sufficient length for the application of any training appliance The best method of teaching writing with the stump during the preprosthetic period is to strap to the forearm a cuff containing a clip into which a pencil may be inserted and rotated to the desired slant and position with relation to the paper Writing is then taught according to the essential principles of the "Palmer Method," that is the use of rotary motions of the pencil impelled by forearm action The size of the characters at first may be large but this can readily be controlled after practice

Use of the telephone. One of the first things that every amputee should learn is how to use a telephone Usually he can simply use his normal hand to hold the receiver However, he will frequently have occasion to perform another task at the same time, such as dialing or jotting down notes or memoranda If a functional prosthesis is worn, it may be used to hold the receiver while the normal hand is occupied, but if such an artificial arm is not used, as in high above-elbow amputation or shoulder disarticulation, some other system must be devised If a French-type phone is used, it can be held firmly between the shoulder and the ear by drawing the shoulder upward and forward against the handle of the instrument This is more easily done if a rubber disc is placed on the handle of the phone When the standing type of telephone is used, the bell-shaped receiver may be held in the same manner described above, but this requires a good deal more practice Some find it easier to place the receiver in the axilla and incline the ear to the diaphragm

When a wrist watch is selected, either the stretch-type or the clip-type metal band is to be preferred Either of these may be put on easily with a little practice

Striking a match Probably the most convenient way for an upper extremity amputee to light a fire or a cigarette is to use a cigarette lighter or a "kitchen match" of the nonsafety variety, which can be struck on the sole of the shoe or some other rough surface However, he may be required at some time or another to employ a paper, book-type match The simplest method of igniting one of these is as follows Hold the match book in the palm of the hand, fold back the covers, bend one match out, preferably from the center of the book, and close the book tightly by sliding the cover back into position with only the one match out With the thumb on the tip of the match, fold the match in half with the index finger so that the head of the match falls in position on the striking surface Then hold the match book in position between the middle and index fingers and the distal end of the palm, and strike the match by passing its head over the striking surface with a quick light sweep of the thumb The motion is slightly upward so that the thumb will not remain on the ignited head The match head will spring away from the sulfur strip because of the spring action of the folded paper stick Two precautions should be noted (1) always close the match book completely before striking to avoid catching the whole book on fire, and (2) do not use slow, heavy pressure since the thumb may be burned in this manner

A

B

Fig 532 — *A* and *B*, In eating, the hook may be used to stabilize either knife or fork Since rotation of the forearm is important in the use of the knife, the normal hand is usually used for this task and the hook is used to hold the fork (as in *A*) In *B*, the amputee holding the knife in the hook has a wrist disarticulation and has retained much of his normal pronation and supination (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

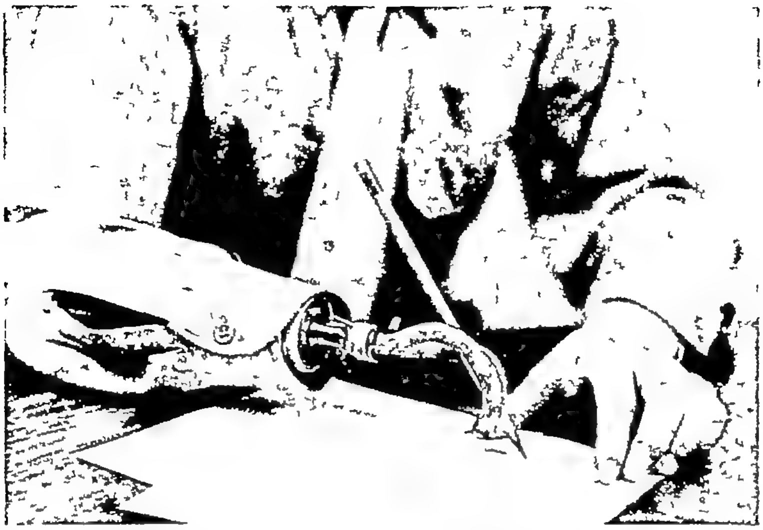

Fig. 533.—The prosthetic arm is used for writing while the normal hand is used to stabilize the paper. It is usually preferable to retrain the prosthetic arm for this task when it is the dominant extremity. (Courtesy of Visual Aids Center, Army Medical Center, Washington, D. C.)

Fig. 534.—The normal hand is used for writing while the paper is stabilized by a convenient weight made of a brass bar and a drawer pull. This patient preferred the normal hand in spite of the fact that it was not the dominant one because of his difficulty in using the above elbow prosthesis. (Courtesy of Visual Aids Center, Army Medical Center, Washington, D. C.)

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Figs 535 and 536—In using the telephone the instrument may be held to the ear with either the prosthesis or the shoulder The normal hand can then be used for taking notes or dialing (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

Fig 537—Three ways of striking a paper book match are demonstrated first, by holding the match book in the hook and striking the match with the normal hand, second, by holding the book with the normal hand and striking the match with the hook, and third, by the one handed method described in the text (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

Fig 538—In playing cards, the cards may be held with the hook, with the artificial hand, or in a special rack or ordinary box (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

Fig 543

Fig 544

Fig 545

Fig 546

Fig 547

Fig 548

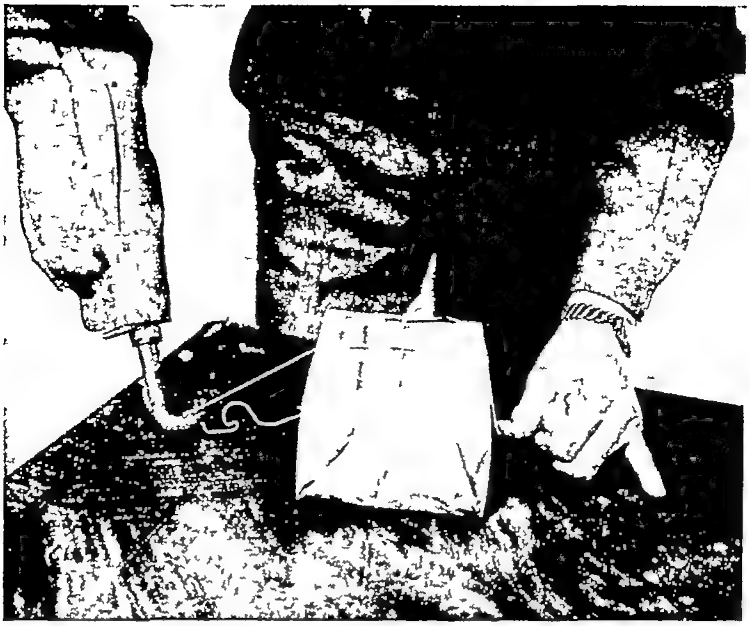

Fig 549

Fig 550

ARMY MEDICAL CENTER
Walter Reed General Hospital — Occupational Therapy Department
Washington 12, D C

UPPER EXTREMITY AMPUTATION ACHIEVEMENT RECORD

NAME (LAST FIRST MIDDLE INITIAL)	GRADE	ARMY SERIAL NUMBER

SITE OF AMPUTATION	DATES: FIRST VISIT	DATES: PROSTHESIS RECEIVED	DATES: DISCHARGED

☐ SINGLE ☐ DOUBLE ☐ DOMINANT

☐ OTHER DISABILITY (SPECIFY)

CIVILIAN OCCUPATION AND INTERESTS

PINGPONG WITH CUFF	LEATHER PROJECT
WRITING AND TYPING WITH CUFF	WOODWORK PROJECT
WRITING WITH LEFT HAND	PROJECT IN WEAVING CORD KNOTTING OR PLASTICS
WRITING WITH PROSTHESIS	PLAY CHECKERS — — FLOOR OR TABLE
PINGPONG WITH PROSTHESIS	THROW DARTS OR HORSESHOES
TYPING WITH PROSTHESIS	SHINE SHOES
DIAL AND ANSWER PHONE AND TAKE DOWN MESSAGES	CLEAN FINGERNAILS USE HANDBRUSH
DEPOSIT COIN IN TOKEN BOX	PUT ON AND BUCKLE BELT
FOLD BUSINESS LETTER CLIP AND PUT IN ENVELOPE	PUT GLOVE ON GOOD HAND
OPEN SEALED ENVELOPE AND TAKE LETTER OUT	SEW ON BUTTON
OPERATE PENCIL SHARPENER FILL FOUNTAIN PEN	USE SAFETY PIN
OPEN AND CLOSE WINDOWS AND DRAWERS	WIND AND PUT WATCH ON
OPEN DOOR WITH DOUBLE LOCK	OPEN VARIOUS BOTTLES USE CAN OPENER
USE KNIFE AND FORK	ADJUST BABY CRIB
PICK UP CUPS AND GLASSES	ADJUST VENETIAN BLINDS
TIE SHOE LACES	WASH AND DRY DISHES
TIE NECKTIE	USE BROOM SHOVEL AND GARDENING TOOLS
COMB HAIR AND SHAVE	CARRY TRAY
BUTTON BUTTONS	USE EGGBEATER
TURN TYPES OF LIGHT SWITCHES ON AND OFF	OPEN DOOR & USE KNOBS ON STOVE AND REFRIGERATOR
LIGHT CIGARETTE SAFELY WITH MATCH OR LIGHTER	WRAP PACKAGE
TURN FAUCETS ON AND OFF	HANG PICTURE

SPMEC WR FORM 207
19 OCT 1945

(OVER)

Fig 551 — An upper extremity amputation achievement record

MOVE FURNITURE		CUT PAPER WITH SCISSORS	
USE YALE LOCK		REMOVE AND REPLACE SHIRT ON HANGER	
LOCK DOOR WITH KEY		USE RADIO AND PHONOGRAPH	
USE STREET CAR STRAP		REPAIR ELECTRICAL DEVICE	
OPEN MAP		SPORT ADAPTATIONS	
WIND CLOCK		DRIVING	
USE CAMERA		ADDITIONAL CLASSES	

WOODWORKING ☐ LAYOUT

☐ SAWING ☐ PLANNING ☐ FILING

☐ SANDING ☐ DRILL ☐ HAMMER

☐ SCREW DRIVER ☐ NAIL SET ☐ POWER MACHINERY

USE OF HAND ☐ HOLD PLAYING CARDS

☐ CARRY SUITCASE ☐ CARRY TRAY

☐ SHARPEN PENCIL ☐ POISE

REMARKS

FINAL TEST (TIME LIMIT - ½ HOUR)	I	II	III
DIALING PHONE			
LIFT RECEIVER AND WRITE MESSAGE			
OPEN DOOR WITH DOUBLE LOCK			
TIE SHOE LACES			
WRAP PACKAGES			
BUTTON BUTTONS AND USE ZIPPER			
FILL GLASS WITH WATER			
SHARPEN PENCIL			

REMARKS

Fig 551 (Cont'd)

XIII. THE AMPUTEE AND SPORTS

Sports play a definite role in the rehabilitation of both the upper and the lower extremity amputee. They develop a general sense of well-being and vigor, and improve strength, speed, endurance, balance, coordination, and agility, benefits derived by any participant in such activities, but of inestimable value to the amputee. In addition, from a medical viewpoint they serve as (1) therapeutic exercises for specific muscle groups, (2) as measures to promote balance and coordination, and therefore further training in the use of the prosthesis, and as (3) a psychiatric measure to aid in the patient's mental and social rehabilitation. When the surgeon gives a sports prescription, he must consider these factors and at the same time endeavor to ascertain that the activities are such that they will interest and hold the attention of the patient.

Certain general rules should underlie the sports program.

First, the sports must be geared to the patient's stage of convalescence. In the period prior to the final-type amputation, many sports can be engaged in, such as ping-pong and bicycle riding for the upper extremity amputee, and certain gymnasium activities for the lower extremity amputee (use of the rowing machine, bag punching, etc.). Following the completion of the final amputation, the field of possibilities widens, but caution must be used in encouraging sports until the wound is soundly healed, and then care should be taken to choose activities which will not cause the stump to break down with the demands of increased use, and to avoid sports which would tend to overstrengthen dominant muscles and accentuate a deformity.

Second, the activities required should be chosen in accordance with the patient's age and capabilities, and should be progressive in nature. It is generally appreciated that in older individuals coordination and physical rehabilitation are slower than in the young, and that the capacity of all healthy individuals is not equal. True athletic prowess is the goal hoped for, but not attained by the rank and file, and it is well to instill this idea into the patient who is psychiatrically unstable. The sports program for the amputee should be planned to encourage, and should start with the milder forms of exercise and should build up gradually to the more strenuous and more exacting. The activities chosen should be those in which he may expect most satisfying achievement, and stress should be placed not upon attaining the perfection displayed by the professional athlete or acrobat, but rather upon the enjoyment of sports as a matter of physical training and relaxation.

Third, training and practice are essential if the additional balance and coordination required because of the physical handicap are to be gained, and proficiency attained. Thus, the well-directed sports program will encourage good dietary and rest habits, will plan well-spaced practice periods, at first of short duration and later more prolonged, and will provide periodic checks on achievement and proper stress on good form.

Lastly, a positive sports consciousness must be created, for only by the patient's sustained interest can sports therapy be carried over into his everyday life as healthful recreation.

Fig 552—Golf is one of the most popular of all sports for the amputee For the upper extremity it is an excellent training measure because of the balance, rhythm, and coordination which it requires For the lower extremity it is used to teach lateral stabilization of the prosthesis It is usually well to start in the early preprosthetic period with the milder forms, such as putting, and to take up driving and full swinging with the club later when the stump becomes tougher and breakdown is less to be feared When the stump is mature and the prosthesis has become well adapted, the patient may start the actual play of the game Here additional benefit is derived by the lower extremity amputee, for he is carried over all types of terrain and is therefore subject to varying walking conditions This bilateral amputee with short below knee stumps reveals the excellent balance and lateral stabilization which may be attained (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

Fig 553 —Golfing aids and gadgets frequently make the play of the game less fatiguing, the use of the portable golf stool to rest while waiting between shots and the use of clubs with interchangeable heads to eliminate the necessity for carrying a golf bag lessen the physical exertion required, and thereby add to the enjoyment of the game (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

?ig 554—Swimming is one of the best all around physical conditioners, and a sport is enjoyed by almost every amputee Although an amputee who has lost but a single nity needs no special aids, the bilateral lower extremity amputee will frequently find ie of special "flippers" of definite value in gaining speed and mobility in the water tesy of Visual Aids Center, Army Medical Center, Washington, D C)

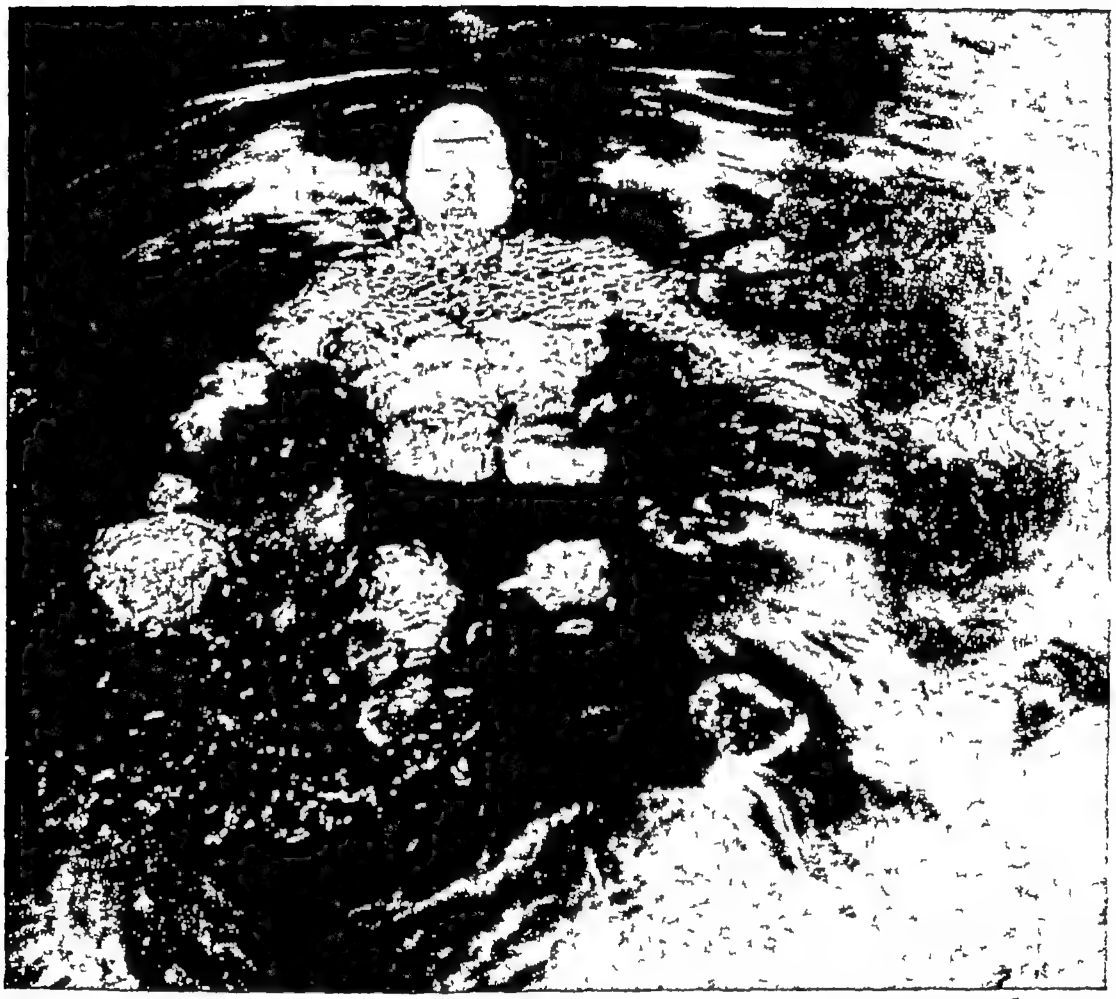

Fig 555—Aquatic play This patient attained proficiency at backstroke, breaststroke, crawl, and in swimming with the surf board (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

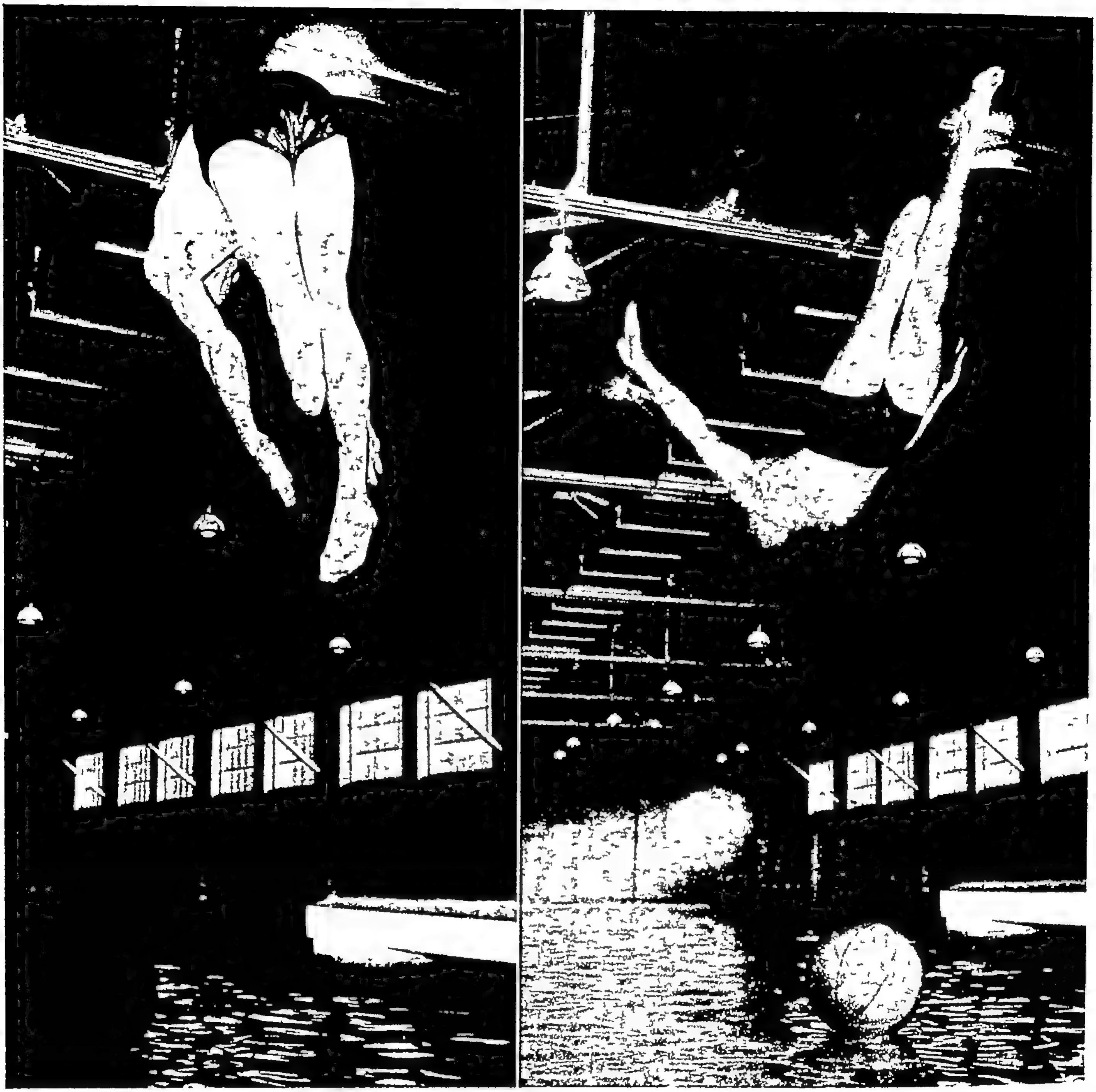

Fig 556—Diving requires exceptional coordination and development It is an excellent training measure for those who have a natural aptitude Stress is placed on proper form and on development of the normal leg Note the height above the board to which this below knee amputee is able to rise (Courtesy of Visual Aids Center, Army Medical Center, Washington, D C)

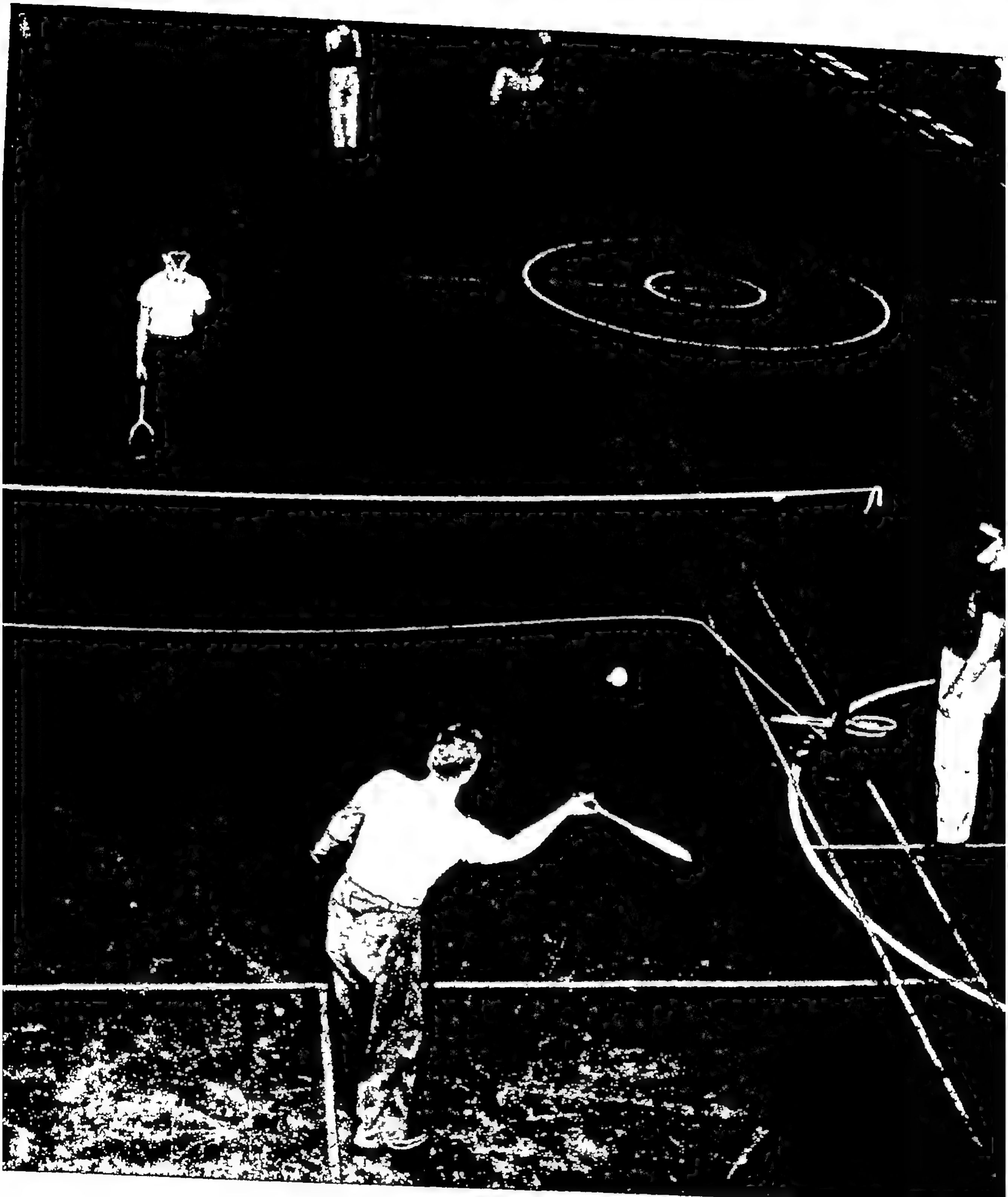

Fig 558 *(For legend see opposite page)*

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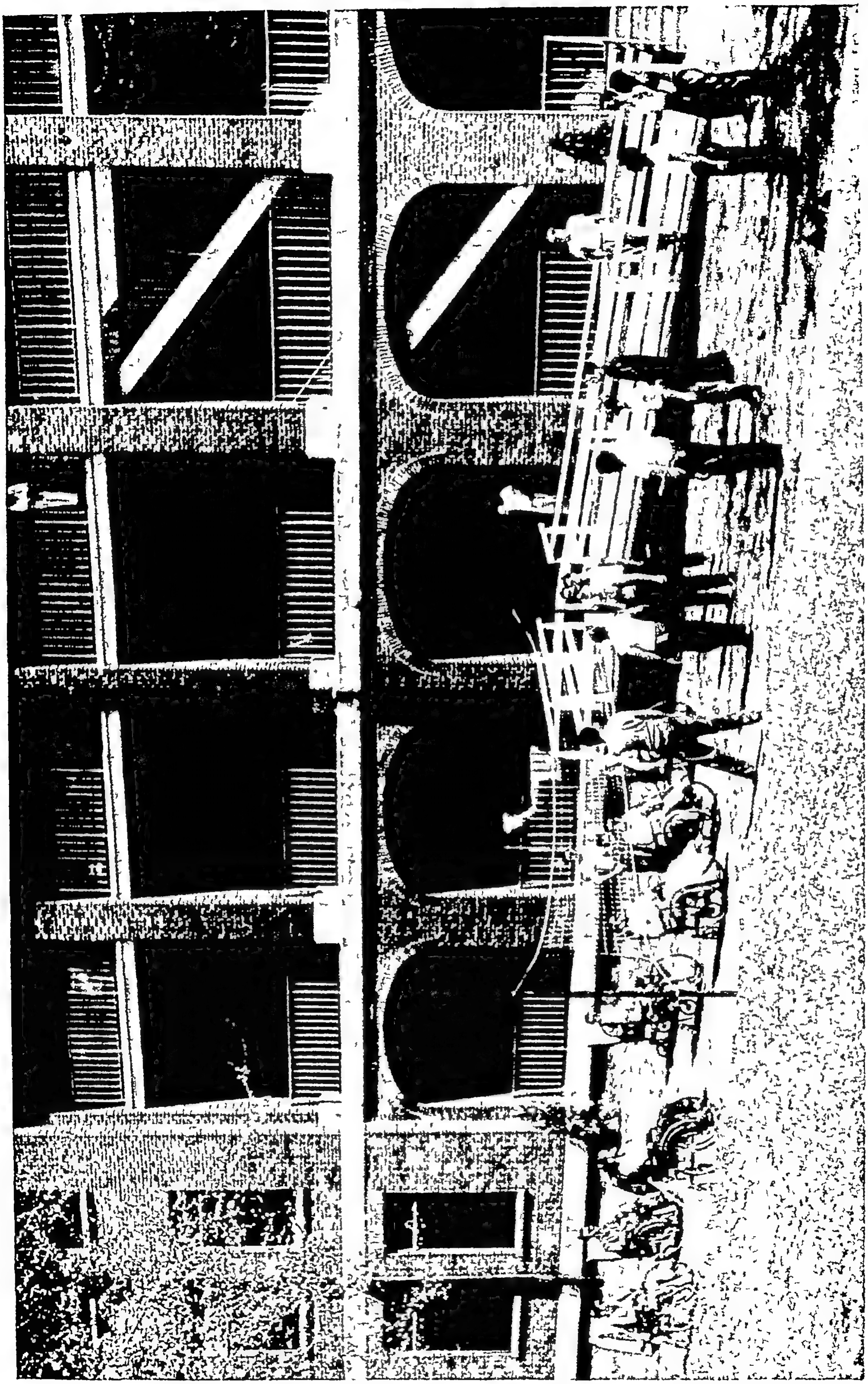
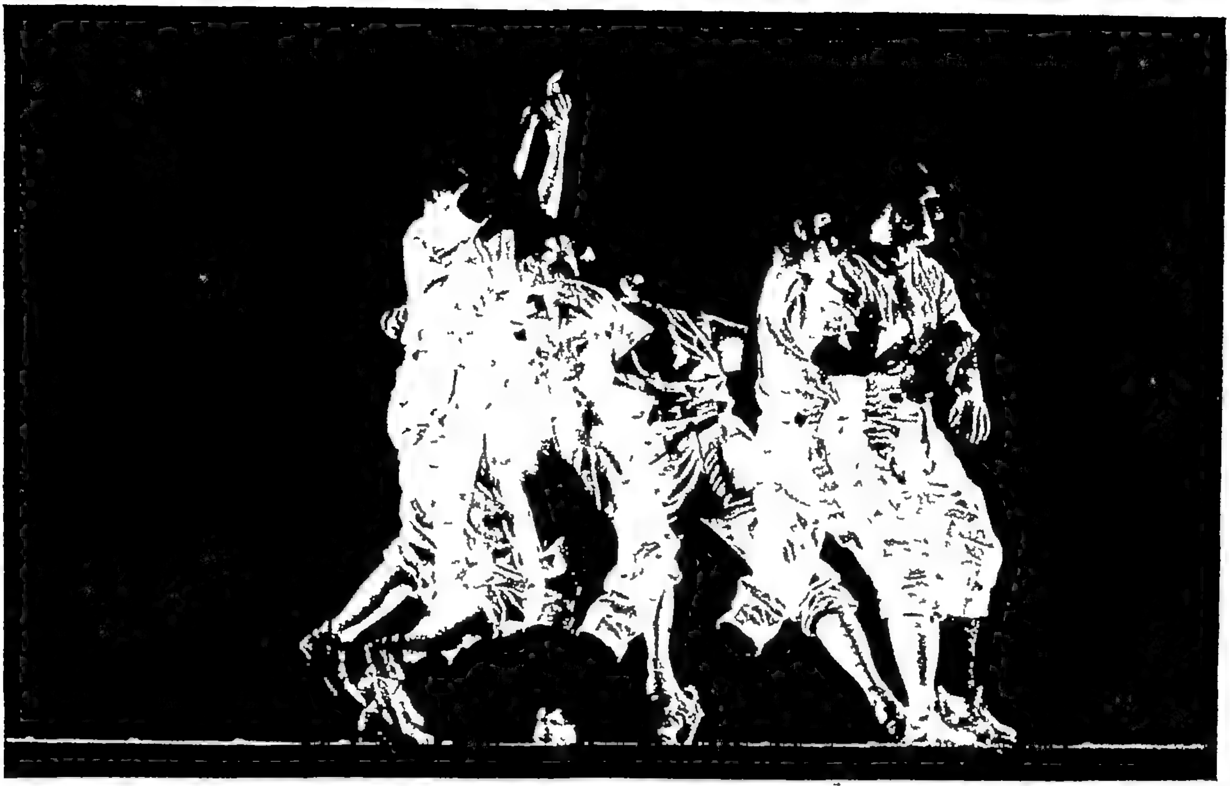
Figs 558 560 —The upper extremity amputee is often able to engage in sport soon as he is up and about Since development of a remaining normal extremity is an portant part of the retraining of the patient, it is desirable that he start as early as sible, even though an artificial member is not worn, although balance is usually be with the use of a prosthesis Badminton, baseball, and bicycle riding are demonstr here It is interesting to note that the above elbow amputee, in catching and throw the ball, usually catches the ball with the normal hand, places the glove between st and body, and then throws with the normal hand (Courtesy of Visual Aids Center, A Medical Center, Washington, D C)





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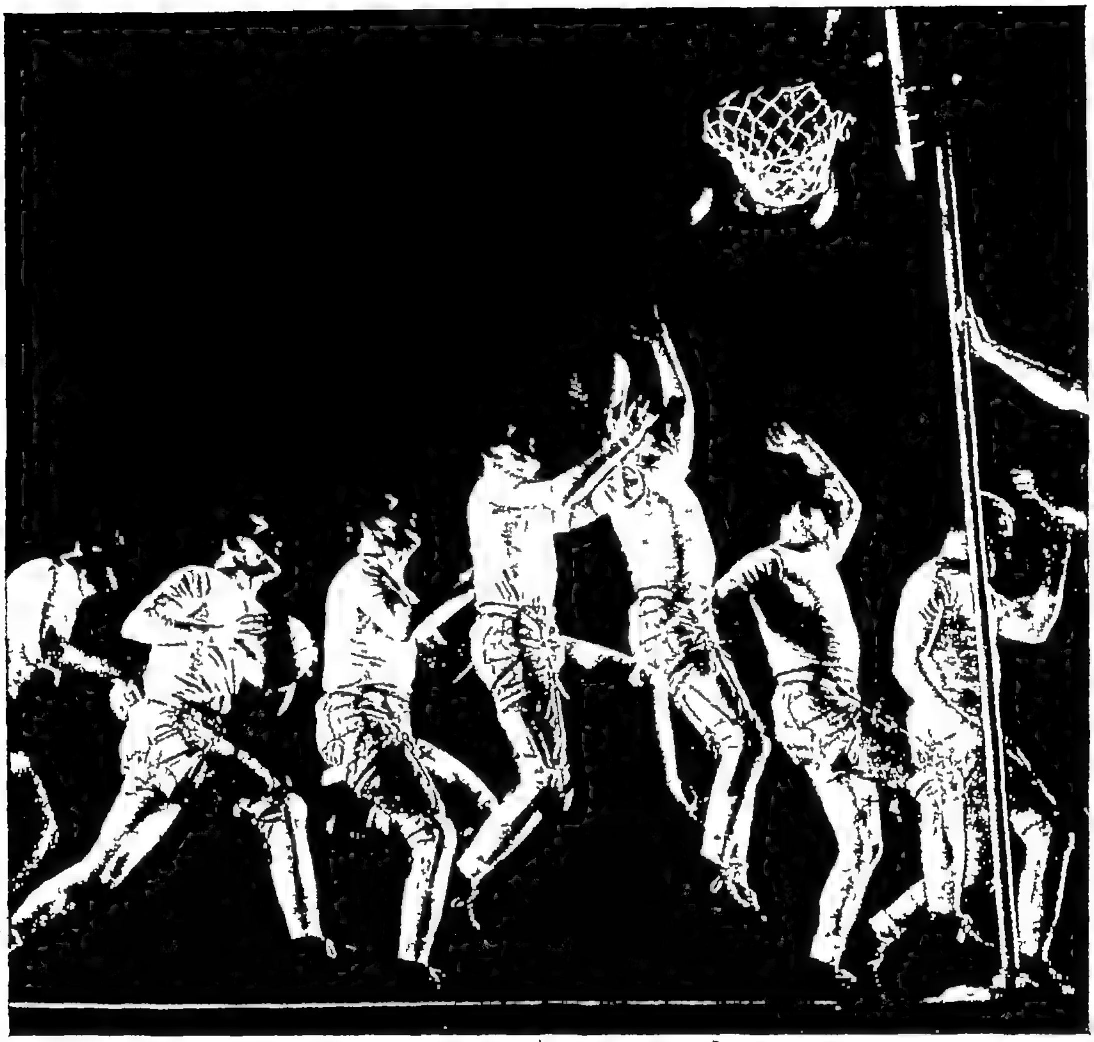
Figs 562 and 563 *(For legend see opposite page)*



564

Figs 562 564 —A trained athlete may gain unusual sports skill in highly competitive games It is the rare individual who can play baseball, run, or field a basket like this below-knee amputee who epitomizes thorough training in combination with natural aptitude (Courtesy of Gjon Mili)

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